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LABORATORY MANUAL OF COMPARATIVE ANATOMY OF VERTEBRATES

AS PER NEP-2020 (2.0) SYLLABUS OF SHIVAJI UNIVERSITY, KOLHAPUR

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PREFACE

Practical learning forms the bedrock of biological sciences, particularly in Zoology. While theoretical frameworks provide us with the conceptual understanding of life, it is in the laboratory where these concepts come alive through observation, structural analysis, and comparative study. This laboratory manual is precisely tailored to meet the curriculum requirements of the B. Sc. Third Year Zoology students, serving as a comprehensive, structured guide for their practical journey into vertebrate anatomy.

The evolutionary transition of vertebrates from simple aquatic life forms to highly specialized terrestrial and aerial organisms is one of the most fascinating chapters in biology. This book adopts a systematic, comparative approach to guide students through this evolutionary journey. By analyzing structural modifications across the five major vertebrate classes through detailed vertical sections (V.S.) of skin, complex internal organ systems, skeletal frameworks, and epidermal derivatives, students can trace how nature re-engineered basic anatomical plans to meet diverse ecological demands.

We are immensely grateful to our fellow academic collaborators, colleagues, and the institutional leadership whose consistent support and insights have greatly enriched the quality of this work. We would also like to acknowledge our students, whose classroom interactions and practical challenges provided the primary inspiration for crafting a highly focused, learner-centric manual.

It is our sincere hope that this book will not only help students excel in their practical examinations but also kindle a deeper curiosity for research, morphology, and the evolutionary marvels of the animal kingdom.

Suggestions for further improvement from teachers and students will be warmly appreciated.

- Authors

LABORATORY MANUAL OF

COMPARATIVE ANATOMY OF VERTEBRATES

B. SC. III ZOOLOGY (NEP-2.0)

SEMESTER V

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1. V. S. of the skin of vertebrates

2. Digestive system of vertebrates

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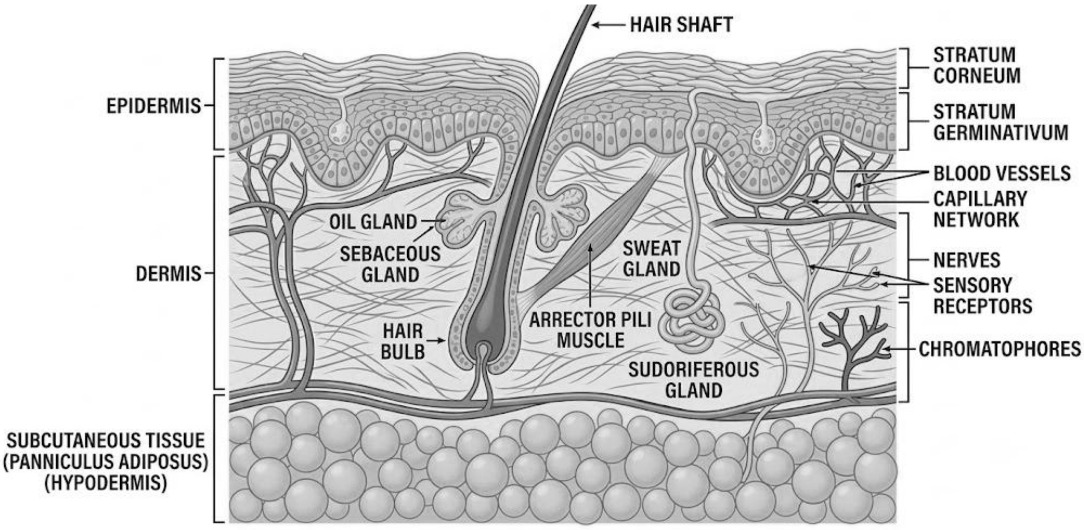
COMPARATIVE STUDY OF THE V. S. OF THE SKIN OF VERTEBRATES

General Account of Vertebrate Skin

The vertebrate integument (skin) is a continuous external body covering that serves as a protective barrier between the internal systems and the external environment. Structurally, it is a compound organ built upon a consistent dual-layered blueprint across all vertebrate groups.



V. S. of Vertbrate Skin

1. Primary Structural Layers

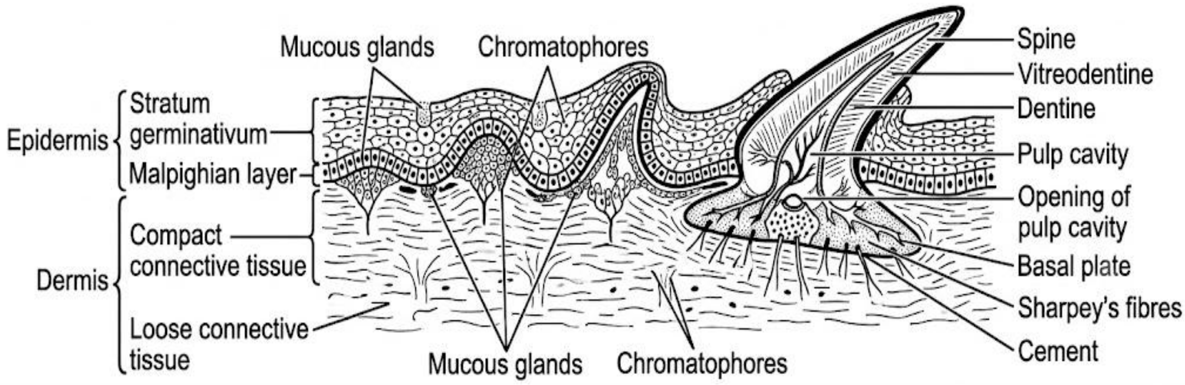
Epidermis (Outer Layer):

- Derived from the embryonic ectoderm.
- Consists of stratified squamous epithelium arranged in multiple cellular tiers.
- The basal layer, the Stratum Germinativum (Malpighian layer), rests directly on the basement membrane. It undergoes continuous mitotic division, pushing older cells outward toward the surface.
- As cells move outward, they undergo keratinization (accumulation of the fibrous protein keratin), creating a specialized outermost barrier—the Stratum Corneum—in terrestrial forms to restrict desiccation.

Dermis (Inner Layer):

- Derived from the embryonic mesoderm.
- Typically, much thicker than the epidermis, composed of a dense matrix of connective tissue, collagenous fibers, and elastic fibers.
- It serves as the metabolic and sensory hub of the skin, housing blood capillaries, lymphatic vessels, nerve fibers, sensory receptors, and smooth muscle bundles.
- It contains chromatophores (pigment cells containing melanin, carotenoids, or purine crystals) responsible for body coloration, camouflage, and UV protection.

A. V. S. of Skin of Scoliodon (Cartilaginous Fish / Chondrichthyes)



V. S. of Skin of Scoliodon

Epidermis

- **Stratified but thin:** Composed of a few layers of non-keratinized stratified epithelial cells.
- **Absence of Stratum corneum:** Being entirely aquatic, it completely lacks a dead, keratinized outermost layer (*stratum corneum*) and does not undergo moulting.
- **Malpighian Layer:** The innermost basal layer (*stratum germinativum*) consists of actively dividing columnar cells resting on a distinct basement membrane.

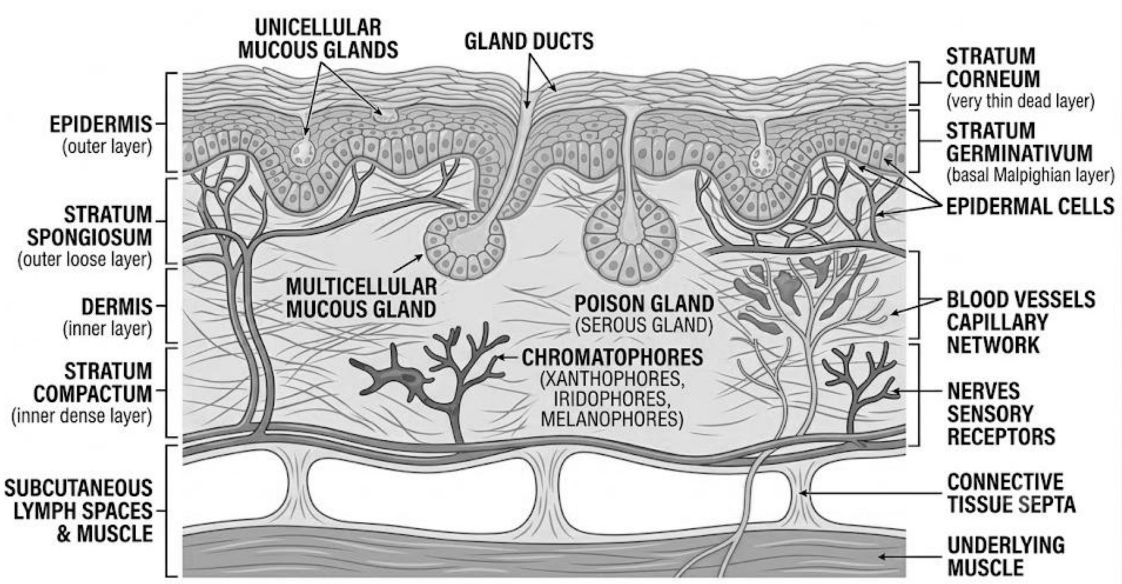
Dermis

- **Differentiated Layers:** Distinctly divided into an outer, loosely arranged Stratum spongiosum and a deeper, thick, densely packed fibrous Stratum compactum.
- **Glands:** Contains small, specialized unicellular mucous glands (goblet cells) scattered throughout the epidermis that secrete slime to reduce friction and provide osmotic protection. It completely lacks the large, flask-shaped multicellular glands found in amphibians.
- **Chromatophores:** Abundant, specialized pigment cells concentrated primarily at the dermo-epidermal junction, responsible for the shark’s counter-shading camouflage.
- **Exoskeleton Anchor:** Contains numerous microscopic placoid scales embedded firmly within the dermis by a bony basal plate, with their sharp dentine spines projecting backward through the epidermis.

Key Identification Feature

- Presence of backwardly directed, tooth-like placoid scales containing a central pulp cavity, anchored within a distinct two-layered dermis beneath a non-keratinized epidermis.

B. V. S. of Skin of Frog (Amphibia)



V. S. of the Skin of Frog

Epidermis

- **Stratified and Thin:** Composed of a few layers of stratified epithelial cells that flatten toward the surface.
- **Stratum Corneum:** The outermost tier consists of dead, flattened, keratinized cells, which are shed periodically during moulting.
- **Stratum Germinativum:** The innermost basal layer contains actively dividing columnar cells resting on a distinct basement membrane to regenerate upper layers.

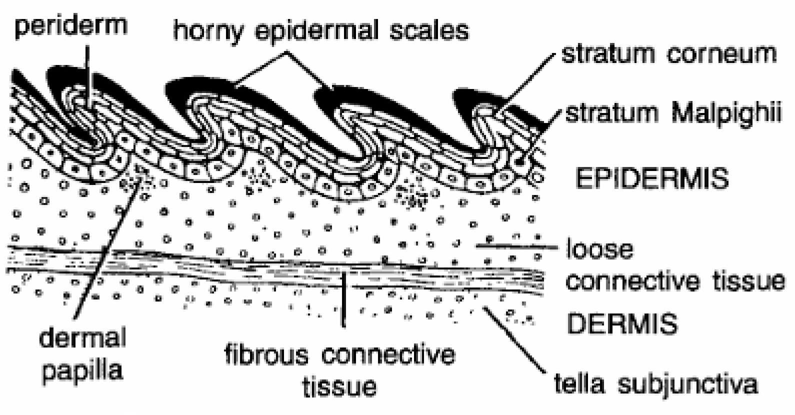
Dermis

- **Stratum Spongiosum:** The outer, loose connective tissue layer hosting a rich network of blood capillaries for cutaneous respiration.
- **Stratum Compactum:** The deeper, thick layer packed with dense, horizontal collagen fiber bundles providing structural strength.
- **Multicellular Glands:** Abundant, flask-shaped glands embedded in the spongiosum that open via epidermal ducts. These include smaller mucous glands for moisture and larger poison glands for defense.
- **Chromatophores:** Specialized pigment cells concentrated at the dermo-epidermal junction, responsible for camouflage.
- **Absence of Scales:** Completely lacks any dermal or epidermal exoskeletal structures.

Key Identification Features

- Presence of large, flask-shaped multicellular glands (mucous and poison) within a distinct two-layered dermis entirely devoid of scales, hairs, or feathers, beneath a weakly keratinized stratified epidermis.

C. V. S. of Skin of Lizard (Reptilia)



V. S. of Skin of Lizard

Epidermis

- **Thick and Keratinized:** Multilayered stratified epithelium adapted entirely for a terrestrial life to restrict water loss.
- **Stratum Corneum:** The outermost layer is highly modified into thick, dead, horny **epidermal scales** that overlap one another. This protective layer is periodically cast off during moulting.
- **Stratum Germinativum:** The innermost basal layer consisting of mitotically active cells that continuously push newer generations outward.

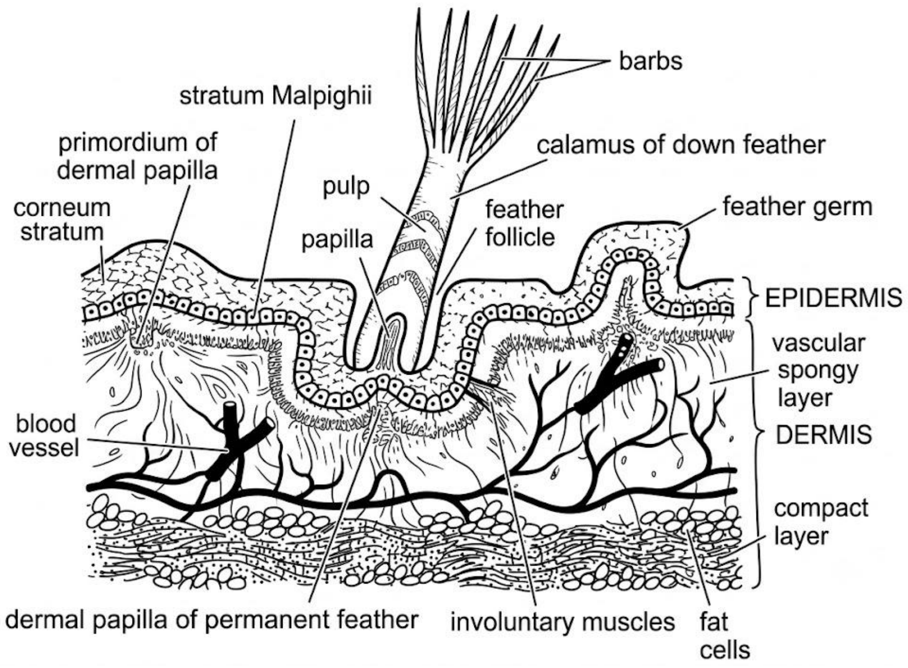
Dermis

- **Two Zones:** Divided into an outer, looser stratum spongiosum containing blood vessels and nerves, and a deeper, dense stratum compactum packed with thick collagen fiber bundles.
- **Total Absence of Glands:** The skin is completely dry and lacks mucous, sweat, or oil glands.
- **Chromatophores:** Abundant, specialized pigment cells (melanophores) concentrated in the upper dermis. In *Calotes*, these are highly developed, facilitating striking behavioral color changes.

Key Identification Features

- Characterized by an outermost covering of thick, overlapping horny epidermal scales, a completely dry dermis devoid of any cutaneous glands, and an abundance of prominent dermal chromatophores.

D. V. S. of Skin of Bird (Aves)



V. S. of the Skin of Bird

Epidermis

- **Thin and Delicate:** Composed of a thin, loosely attached multilayered stratified epithelium over most of the body.
- **Stratum Corneum:** The outermost layer is very thin and weakly keratinized, except on the legs and toes where it forms thick epidermal scales and claws.
- **Stratum Germinativum:** The basal layer consists of actively dividing cells resting on a basement membrane, giving rise to highly specialized feathers (epidermal derivatives).

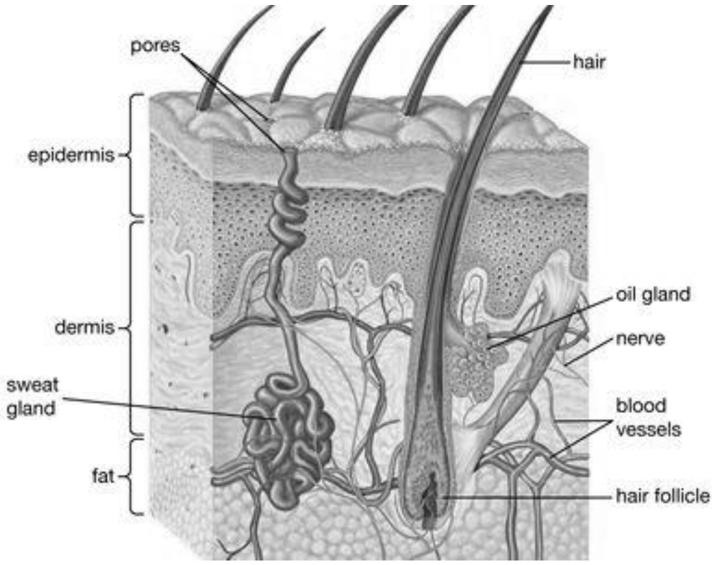
Dermis

- **Layered Structure:** Composed of a superficial stratum spongiosum rich in blood vessels and an inner, dense stratum compactum with crisscrossing collagen fibers.
- **Absence of Cutaneous Glands:** The skin is completely dry and lacks sweat or oil glands. The sole exception is the uropygial (preen) gland located at the base of the tail, which secretes an oily fluid for feather waterproofing.
- **Muscular Network:** Contains specialized smooth muscle fibers (cutaneous muscles) attached to feather follicles to control feather movement for flight and insulation.

Key Identification Features

- Characterized by a thin, delicate epidermis bearing complex feathers or feather follicles, an extensive network of feather-erecting muscles, and a dry dermis completely devoid of localized glands (except the distant uropygial gland).

E. V. S. of Skin of Rabbit (Mammalia)



V. S. of Skin of Mammal

Epidermis

- **Thick and Highly Differentiated:** Formed of a multi-layered stratified squamous epithelium distinctly divided into five cellular strata (*germinativum, spinosum, granulosum, lucidum*, and *corneum*).
- **Stratum Corneum:** The outermost layer is exceptionally thick, dead, and heavily keratinized, providing structural protection against mechanical friction and desiccation.
- **Epidermal Derivatives:** The basal *stratum germinativum* invaginates deeply into the dermis to form complex structures like hair follicles, nails, or claws.

Dermis

- **Highly Complex Zones:** Divided into a superficial papillary layer (*stratum spongiosum*) forming dermal papillae that lock into the epidermis, and a thick, tough reticular layer (*stratum compactum*) packed with dense elastic and collagen fibers.
- **Abundant Cutaneous Glands:** Densely packed with complex, multicellular glands opening to the surface:
- **Sensory and Vascular Hub:** Contains an extensive network of blood capillaries, tactile nerve receptors, and smooth arrector pili muscles attached to hair shafts.
- **Subcutaneous Fat Layer:** Underlain by a prominent layer of adipose tissue (*panniculus adiposus*) for heat insulation.

Key Identification Features

- Characterized by an exceptionally thick, multi-layered epidermis bearing prominent hair follicles, complex sebaceous and sweat glands embedded in a dense dermis, and a distinctive subcutaneous fat layer.

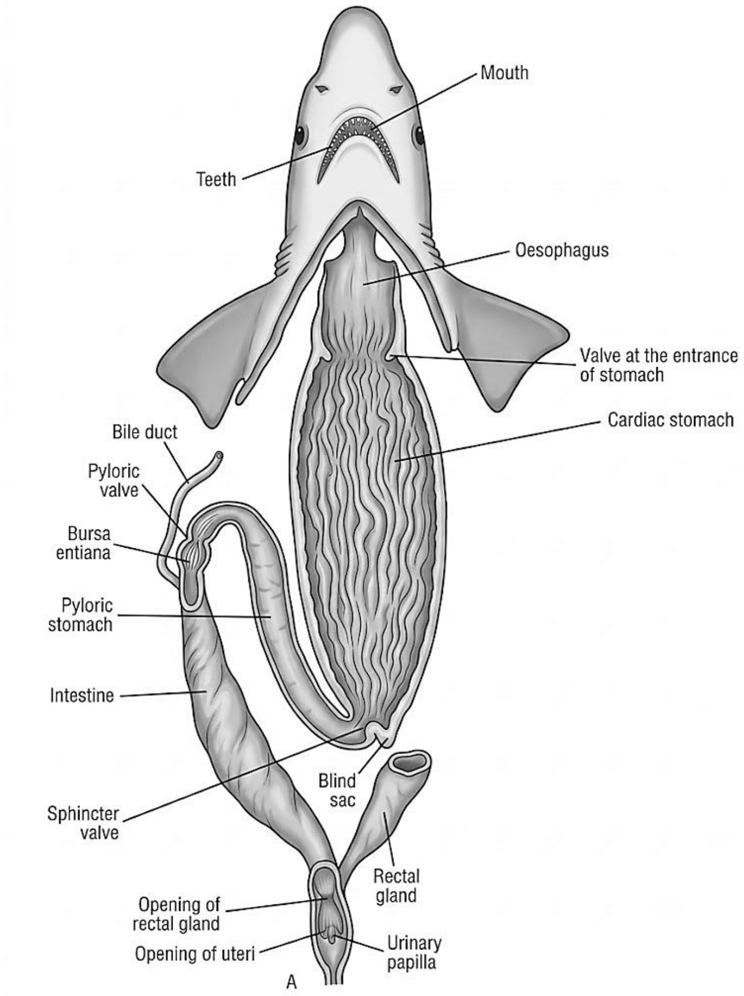
COMPARATIVE STUDY OF THE DIGESTIVE SYSTEM OF VERTEBRATES

The vertebrate digestive system consists of the alimentary canal (a continuous muscular tube running from the mouth to the anus/cloaca) and associated accessory digestive glands (liver, pancreas, and salivary glands). While the fundamental functions of ingestion, digestion, absorption, and egestion remain identical, the system exhibits profound evolutionary modifications. These adaptations reflect a transition from an aquatic to a terrestrial lifestyle, alongside changes in dietary habits from carnivorous to herbivorous regimes.

Building on the comparative anatomy of the vertebrate digestive system, these are the fundamental components shared across classes and their primary physiological functions:

- **Mouth and Oral Cavity:** Responsible for food ingestion, initial mechanical breakdown (mastication via teeth or beaks), and lubrication of the food bolus through salivary secretions.
- **Pharynx:** The common anatomical pathway for both the respiratory and digestive tracts that conducts food from the oral cavity into the esophagus.
- **Esophagus:** A muscular, tubular conduit that utilizes rhythmic peristaltic contractions to propel food from the pharynx downward to the stomach; modified into a crop in birds for temporary food storage.
- **Stomach:** A highly distensible muscular sac that acts as a reservoir for food storage, initiates chemical digestion through the secretion of hydrochloric acid and pepsinogen, and mechanically churns food into a semi-liquid mixture called chyme.
- **Small Intestine:** The primary site for the enzymatic chemical digestion of carbohydrates, proteins, and lipids, as well as the principal zone for nutrient absorption into the bloodstream.
- **Large Intestine (Colon):** Primarily functions in the reabsorption of water, salts, and electrolytes from indigestible food residues, converting liquid waste into solid feces.
- **Liver:** An accessory gland that synthesizes and secretes bile salts to emulsify fats, while also managing nutrient metabolism, detoxification, and glycogen storage.
- **Gallbladder:** A small storage sac that concentrates and stores bile produced by the liver, releasing it into the small intestine during digestion.
- **Pancreas:** Dual-function gland that secretes exocrine pancreatic juices (containing digestive enzymes and bicarbonate ions to neutralize stomach acid) and endocrine hormones (insulin and glucagon) to regulate blood glucose.
- **Cloaca / Anus:** The terminal opening responsible for the elimination of digestive waste from the body.

A. Pisces (e.g., *Scoliodon* / Shark)



Digestive system of Scoliodon

- **Mouth & Jaws:** Wide, crescentic, ventral mouth armed with multiple rows of sharp, homodont (identical), polyphyodont (replaced throughout life) teeth modified from placoid scales. Teeth are used for tearing, not chewing.
- **Pharynx & Oesophagus:** Spacious pharynx pierced by 5 pairs of lateral internal gill slits. The oesophagus is short, wide, and highly distensible.
- **Stomach:** Highly developed and J-shaped. It is clearly demarcated into a wide, anterior cardiac stomach (featuring internal longitudinal folds) and a narrow, posterior pyloric stomach. A muscular pyloric sphincter regulates food transit.
- **Intestine:** Short and straight, but compensated internally by a highly characteristic **Scroll Valve (spiral valve)**. This structure increases the absorptive surface area and slows down food passage without increasing tube length.
- **Terminal Opening:** Opens into a Cloaca (a common chamber for digestive, urinary, and reproductive tracts), which features a rectal gland that secretes excess salt.

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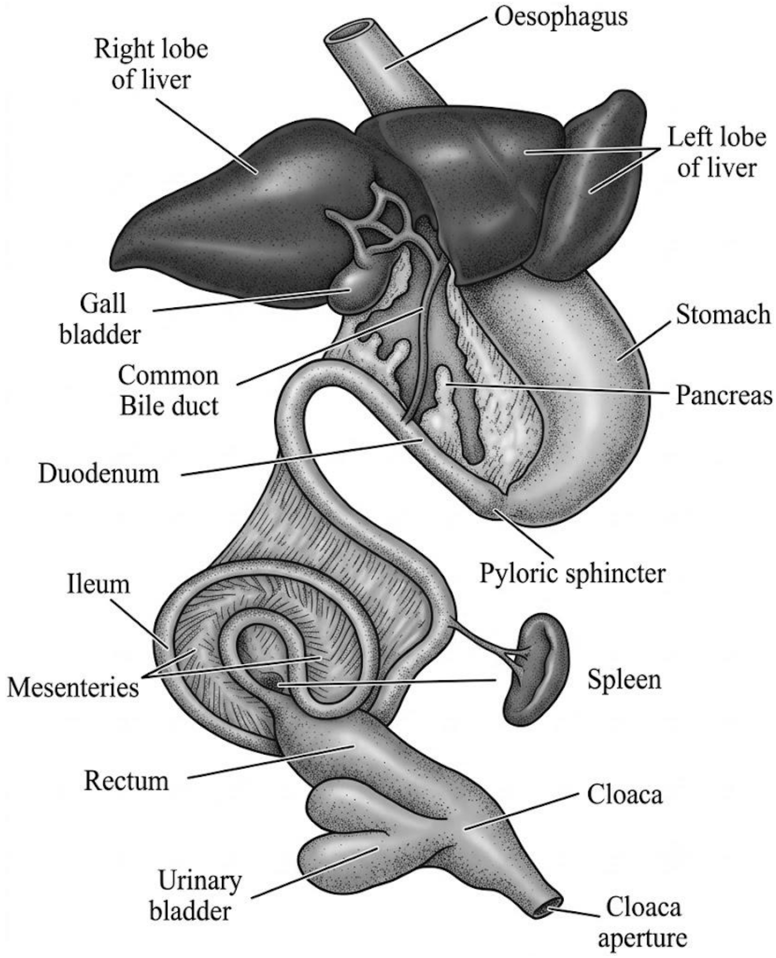
B. Amphibia (e.g., *Frog*)

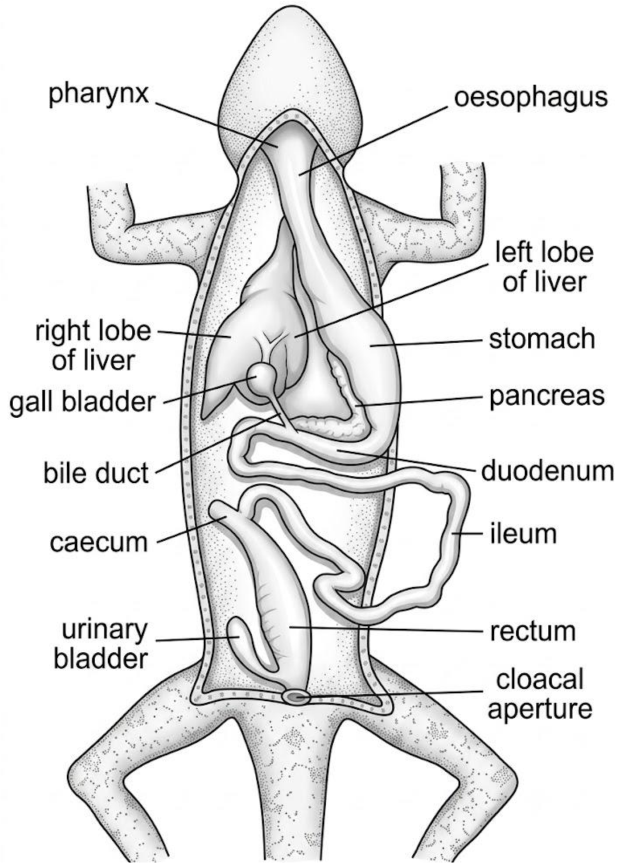


Digestive system of Frog

- **Mouth & Buccopharyngeal Cavity:** Wide terminal mouth. True teeth are absent on the lower jaw; the upper jaw bears small, homodont maxillary teeth, and the roof of the mouth bears vomerine teeth (used only to hold prey). The tongue is large, muscular, sticky, bifid (forked) at the free end, and attached anteriorly for rapid protrusion to catch insects.
- **Oesophagus:** Short, wide, and muscular, leading directly into the stomach.
- **Stomach:** Unilocular, muscular, and fish-shaped, lying on the left side of the body. It is divided into an anterior cardiac and a posterior pyloric region.
- **Intestine:** Differentiated into a coiled small intestine (duodenum and ileum) and a short, straight large intestine (rectum).

  Note: The internal surface of the small intestine has folds but lacks villi.
- **Terminal Opening:** The rectum opens into a Cloaca, which discharges via the cloacal aperture.

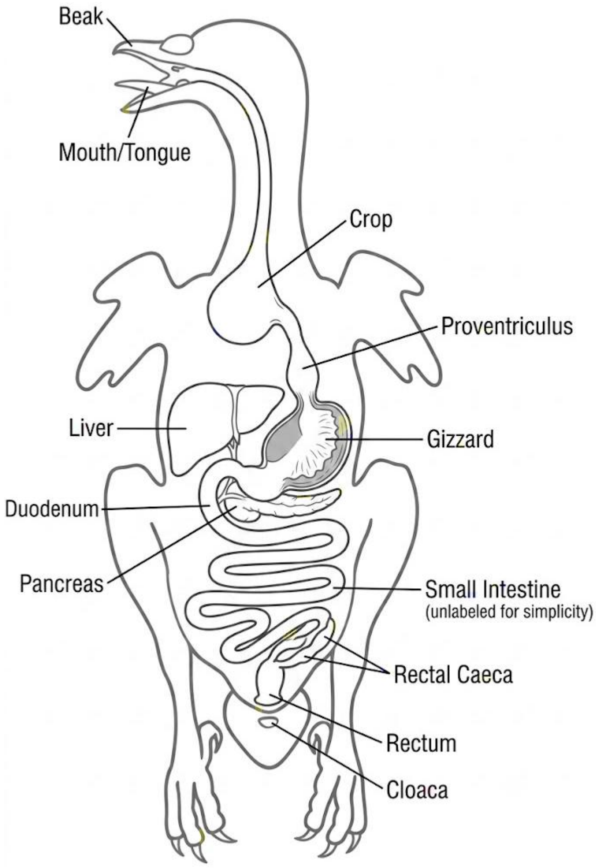
C. Reptilia (e.g., *Calotes* / Lizard)



Digestive system of Calotes

- **Mouth & Buccal Cavity:** Terminal mouth with jaws bearing teeth that are typically homodont, pleurodont, or acrodont (fused to the jaw bone summit). The tongue is mobile, protrusible, and often bifid or pointed, serving both gustatory and tactile functions.
- **Oesophagus:** Distinctly longer than in amphibians due to the evolution of a well-defined **neck**.
- **Stomach:** Elongated, cylindrical, and highly muscular. The division between the cardiac and pyloric regions is visually prominent.
- **Intestine:**
  - **Small Intestine:** Long and coiled, showing an advanced surface area for nutrient absorption.
  - **Large Intestine:** Wider than the small intestine. A small, blind pouch called the Caecum appears for the first time at the junction of the small and large intestines (marking the evolution toward processing diverse diets).
- **Terminal Opening:** Opens into a three-chambered Cloaca (coprodeum, urodeum, and proctodeum).

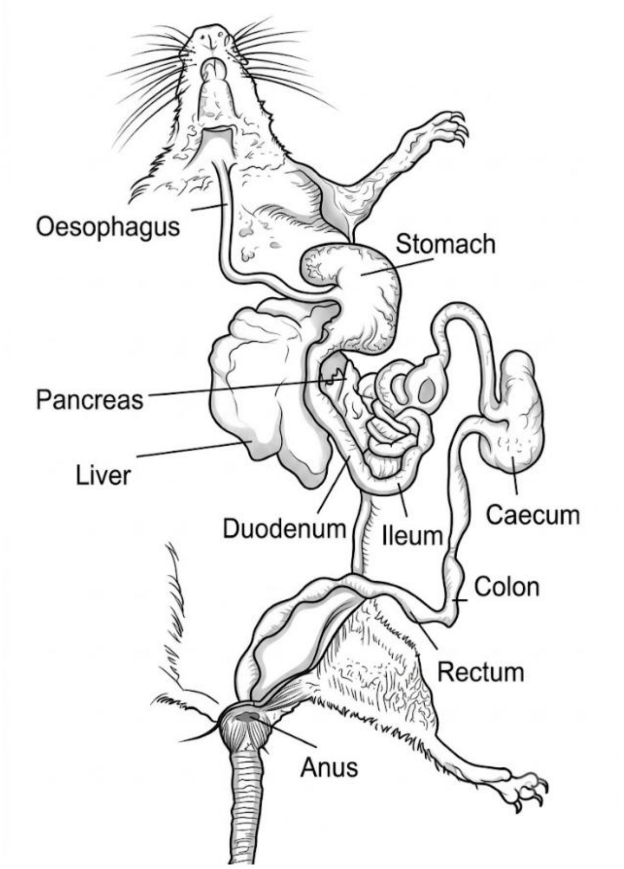
D. Aves (e.g., *Pigeon*)



Digestive system of Pigeon

- **Mouth & Buccal Cavity:** True teeth are completely absent (an adaptation to reduce body weight for flight). Jaws are modified into a horny, keratinized beak. The tongue is narrow, pointed, horny, and lacks significant musculature.
- **Oesophagus & Crop:** The oesophagus is long and expands into a large, thin-walled, bidirectional storage sac called the
- **Crop**. In pigeons, the crop epithelium secretes "crop milk" under prolactin control to feed nestlings.
- **Stomach:** Highly specialized and split into two distinct chambers:
- **Proventriculus (Glandular Stomach):** Anterior, tube-like chamber that secretes gastric juices.
- **Gizzard (Muscular Stomach):** Posterior, thick-walled, heavily muscular disk-like chamber lined internally with a tough keratin-like protein layer. It frequently contains swallowed pebbles (**gastroliths**) used to mechanically grind food, compensating for the lack of teeth.
- **Intestine:** Long and coiled. At the junction of the rectum and small intestine, a pair of small, blind **rectal caeca** is present.
- **Terminal Opening:** Opens into a well-developed Cloaca.

E. Mammalia (e.g., *Rabbit / Rat*)

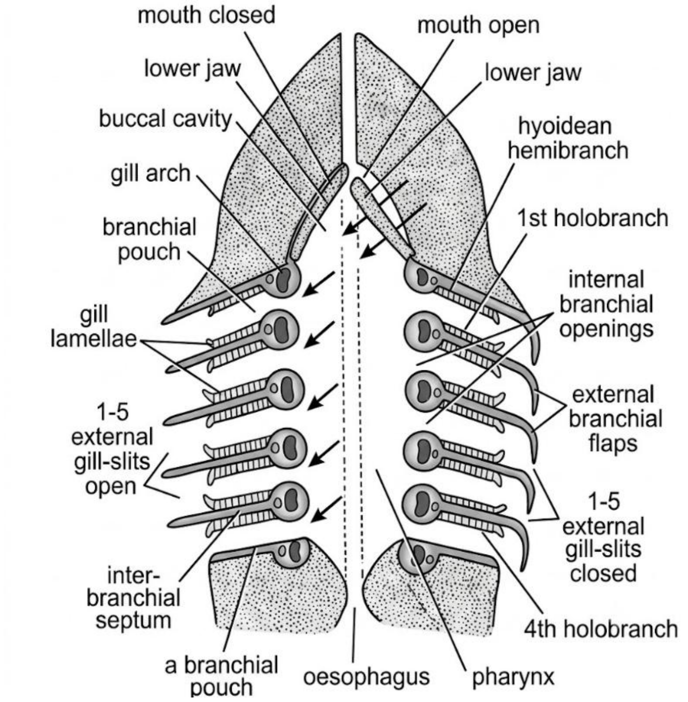


Digestive system of Rat

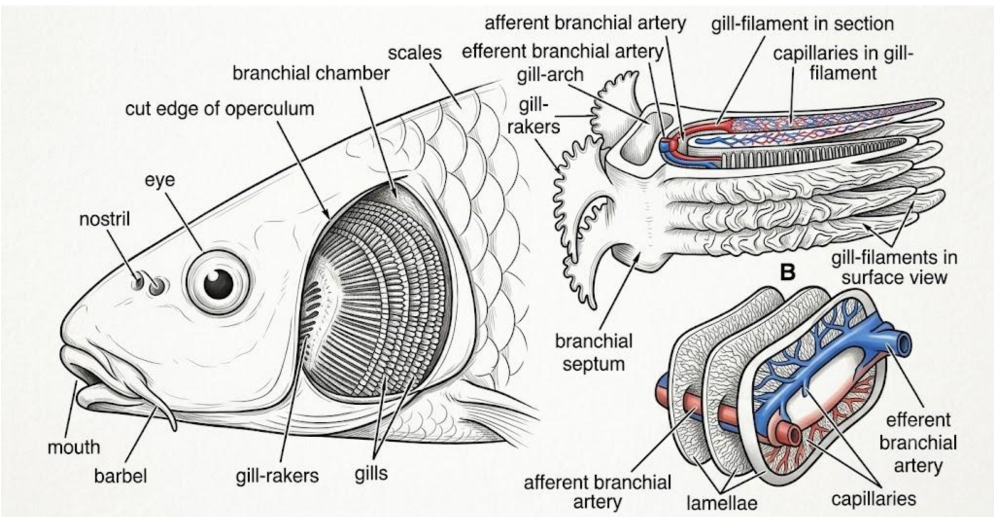
- **Mouth & Buccal Cavity:** Guarded by fleshy, movable lips. Teeth are highly advanced: heterodont (differentiated into incisors, canines, premolars, molars), thecodont (embedded in bony sockets), and diphyodont (two sets: milk and permanent).
- **Oesophagus:** A long, narrow, muscular tube passing through the neck and thoracic cavity, piercing the diaphragm to enter the abdomen.
- **Stomach:** Large, muscular, and sac-like. In herbivores like rabbits, it is a single large cavity; in ruminants, it is complex and four-chambered.
- **Intestine:** Exceptionally long and highly differentiated.
    - **Small Intestine:** Divided into Duodenum, Jejunum, and Ileum. The internal lining contains finger-like villi and microvilli, which vastly optimize nutrient absorption.
    - **Large Intestine:** Consists of the Colon and a massively developed Caecum (in herbivores) ending in a vermiform appendix. The caecum acts as a fermentation vat housing symbiotic bacteria/protozoa to digest cellulose.
- **Terminal Opening:** The digestive tract terminates directly and independently at the Anus. A true cloaca is absent (except in Monotremes).

COMPARATIVE ANATOMY OF RESPIRATORY SYSTEM IN VERTEBRATES

A. Pisces (e.g., *Scoliodon* and Labeo)



Gills in Scoliodon



Gills in Labeo

Fishes rely on gills for branchial respiration. Gills are supported by visceral or gill arches, each bearing two rows of primary gill filaments known as holobranchs. These filaments are covered with thousands of microscopic, highly vascularized secondary lamellae where gas exchange occurs.

In cartilaginous fishes like *Scoliodon*, there are five pairs of individuals, exposed gill slits separated by broad interbranchial septa. In contrast, bony fishes like *Labeo* possess four pairs of gills enclosed within a common opercular cavity protected by a bony operculum.

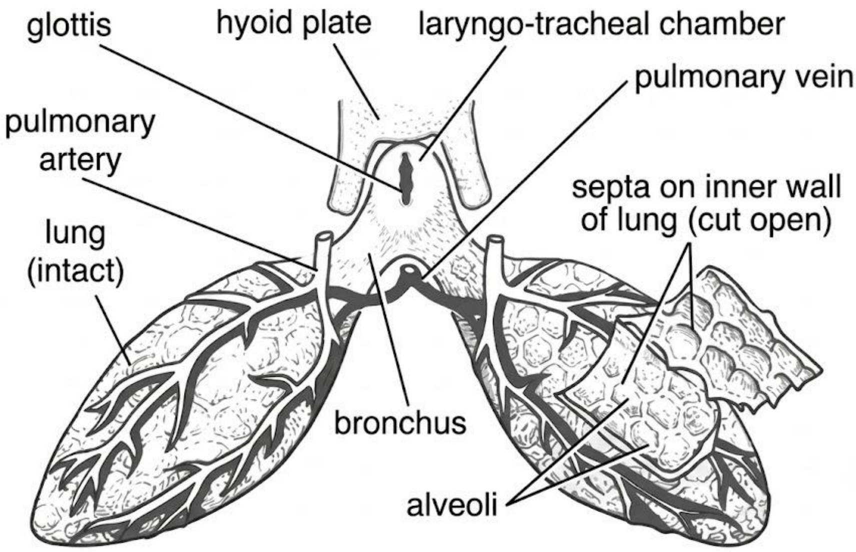
A countercurrent exchange mechanism optimizes gas exchange in fishes. Blood flows through the lamellar capillaries in the direction opposite to water passing over the gills. This maintains a steady oxygen concentration gradient across the entire contact surface, enabling fish to extract up to 90% of dissolved oxygen from the water.

B. Amphibia (e.g., *Frog*)

Amphibians exhibit a transition between aquatic and terrestrial respiration, utilizing three distinct respiratory modes: cutaneous (skin), buccopharyngeal (mouth lining), and pulmonary (lungs).

Cutaneous respiration occurs through thin, moist, and highly vascular skin. This process occurs continuously and serves as the primary mode of gas exchange during aquatic submersion, hibernation, and estivation. Buccopharyngeal respiration relies on the moist lining of the mouth cavity, where oxygen diffuses directly into mucosal blood vessels as the buccal floor rhythmically lowers and raises.

Pulmonary respiration involves a pair of simple, thin-walled, sac-like lungs. The internal walls have minimal partitioning, containing basic honeycomb-like folds called alveoli. Because amphibians lack ribs and a diaphragm, they move air into their lungs using a positive pressure buccal pump. The animal draws air through the nares into the buccal cavity, closes the nares, and raises the floor of the mouth to force air down into the lungs.



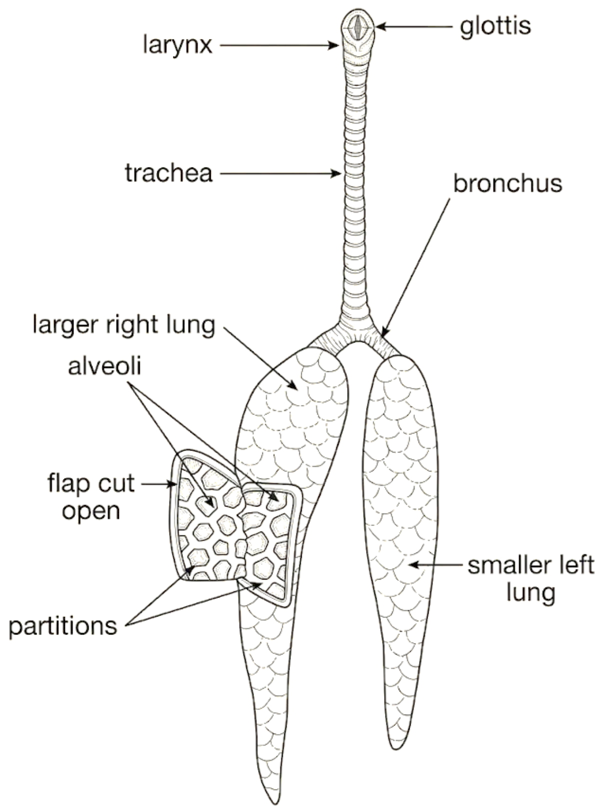
Respiratory System of Frog

C. Reptilia (e.g., *Calotes* / Lizard)

Reptiles rely exclusively on pulmonary respiration due to their dry, keratinized, and scaly skin, which prevents cutaneous gas exchange. Their lungs are fully internal, larger, and far more complex than those of amphibians.

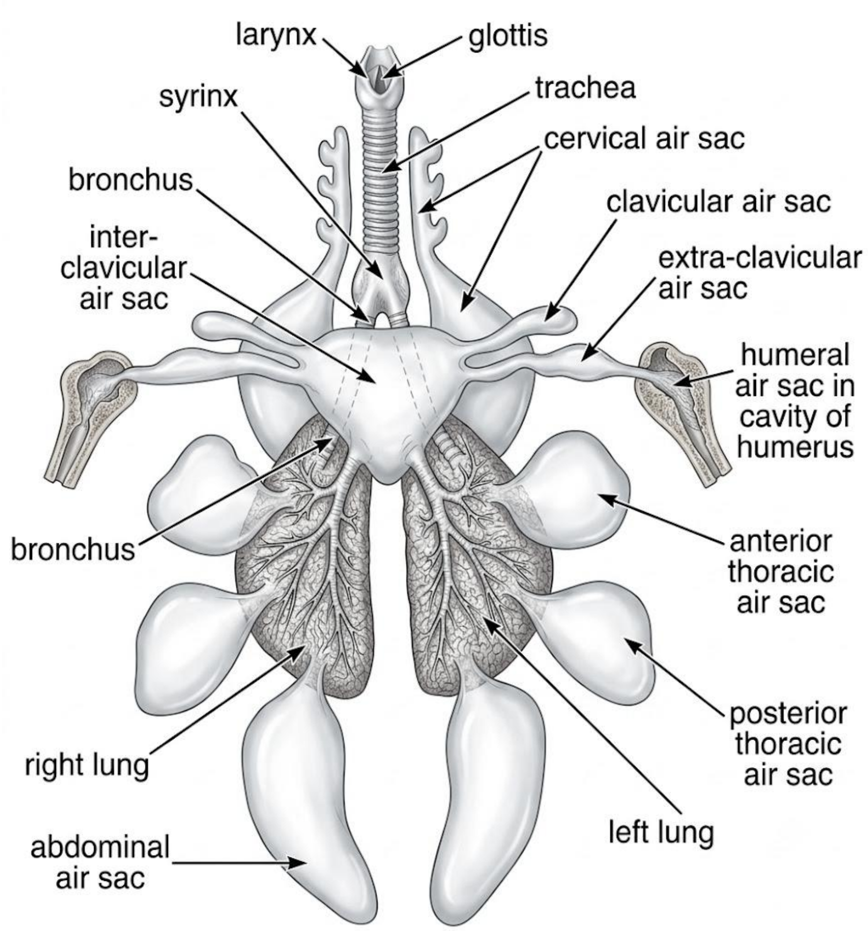
Internally, reptilian lungs are multilocular, divided into several inner chambers by muscular septa and trabeculae. Air travels through a distinct, elongated trachea supported by cartilaginous rings, which bifurcates into two primary bronchi. In snakes, structural adaptations to an elongated body plan have resulted in a reduction or complete loss of the left lung, leaving the right lung fully functional.

Reptiles ventilate their lungs through a negative pressure mechanism. By contracting and relaxing their intercostal rib muscles, they expand and contract the thoracic cavity. This creates a pressure difference that draws air into the lungs during inhalation and expels it during exhalation.



D. Aves (e.g., *Pigeon*)

Birds possess the most complex and efficient respiratory system among vertebrates, adapted to supply high oxygen demands during flight. Their respiratory system consists of small, rigid, non-elastic lungs integrated with a network of thin-walled, non-vascular air sacs.



Respiratory System of Pigeon

The primary lung tissue does not contain blind-ended alveoli. Instead, it features open-ended, tubular channels called parabronchi (air capillaries). Nine thin-walled air sacs (including cervical, interclavicular, thoracic, and abdominal sacs) extend throughout the body cavity and even penetrate hollow bones. These air sacs act as bellows to pump air through the rigid lungs.

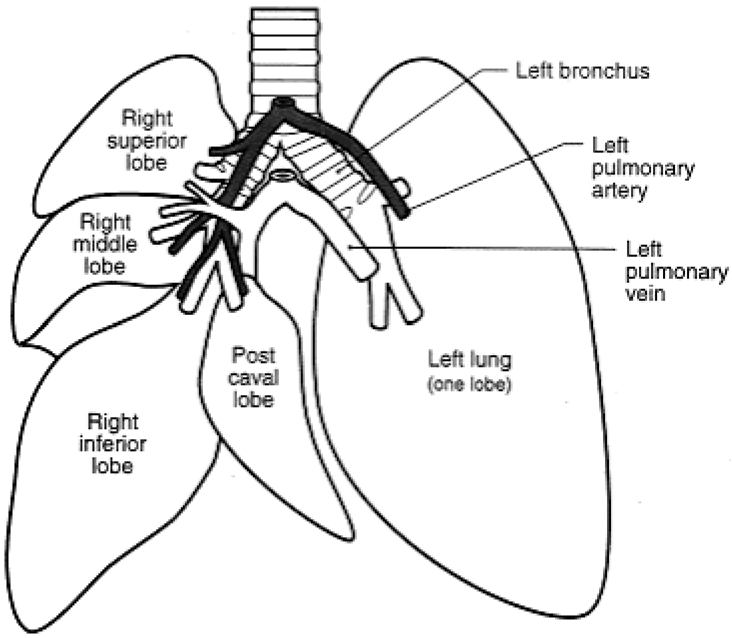
Breathing in birds operates via a unidirectional, two-cycle flow. It requires two complete cycles of inhalation and exhalation for a single volume of air to pass entirely through the system. Air flows through the parabronchi in a continuous, single direction during both inhalation and exhalation, eliminating stale air retention and maintaining constant gas exchange.

E. Mammalia (e.g., *Rabbit / Rat*)

Mammals possess paired, spongy, and highly elastic multilobed lungs enclosed inside a sealed thoracic cavity. The respiratory tract begins at the trachea, which branches into primary bronchi, secondary and tertiary bronchi, and progressively smaller bronchioles, finally terminating in clusters of microscopic sacs called alveoli.

Alveoli serve as the functional units of gas exchange. Millions of these thin-walled sacs are closely wrapped in a dense capillary network, creating an immense internal surface area (approximately 70 to 100 square meters in human lungs) for rapid oxygen diffusion.

Mammalian ventilation uses a negative pressure mechanism driven by the muscular diaphragm and intercostal muscles. Contraction of the dome-shaped diaphragm flattens it downward, expanding the thoracic cavity vertically and creating a suction force that pulls air deep into the alveoli.



Lungs in Rat

Comparative Anatomy Summary

Fishes use gill lamellae with a continuous water flow powered by a positive buccal pump. Amphibians use skin, buccal mucosa, and simple smooth lung sacs powered by positive buccal swallowing. Reptiles rely on septate, multinodular lung chambers ventilated by negative pressure costal rib movements. Birds feature non-expandable lungs with tubular parabronchi and air sacs that drive a continuous unidirectional air flow. Mammals utilize elastic alveolar lungs driven by negative pressure generated by a muscular diaphragm and intercostal muscles.

COMPARATIVE STUDY OF HEARTS VERTEBRATES

The evolution of the vertebrate heart is one of the most prominent examples of structural modification in comparative anatomy. The transition reflects a shift from a single-circuit, aquatic respiratory system to a double-circuit, terrestrial respiratory system. As vertebrates evolved, the heart transitioned from a simple, linear pumping tube that handled only deoxygenated blood to a highly efficient, fully partitioned, four-chambered muscular pump that keeps oxygenated and deoxygenated blood entirely separate.

1. Chamber Configuration and Complexity

- **Fish (2-Chambered):** Consists of one atrium and one thick-walled muscular ventricle arranged in a linear fashion. It also includes two accessory chambers: the receiving sinus venosus and the outflow bulbus/conus arteriosus.
- **Amphibians (3-Chambered):** Features two distinct atria (left and right) and a single, undivided ventricle. The sinus venosus is still present but opens into the right atrium.
- **Reptiles (Incomplete 4-Chambered):** Possesses two atria and a single ventricle that is partially divided by an incomplete interventricular septum (often described functionally as a 5-chambered system in turtles and lizards due to transient internal compartmentalization).
- **Crocodilians, Birds, & Mammals (True 4-Chambered):** Features a completely divided heart with two distinct atria and two completely separated ventricles, eliminating the mixing of blood.

2. Circulatory Circuits

- **Single Circuit (Fish):** Blood follows a single pathway:
  Heart ⟶ Gills (oxygenation) ⟶ Body tissues (deoxygenation) ⟶ Heart.
  The heart only ever pumps deoxygenated venous blood (branchial heart).
- **Double Circuit (Tetrapods):** Separated into a pulmonary circuit (heart to lungs for oxygenation) and a systemic circuit (heart to body for nutrient/oxygen delivery).
  - **Incomplete Double Circulation:** In amphibians and non-avian reptiles, deoxygenated and oxygenated blood mix to varying degrees within the single or partially divided ventricle.
  - **Complete Double Circulation:** In birds and mammals, the pulmonary and systemic systems are completely isolated, ensuring only fully oxygenated blood reaches the systemic tissues.

3. Aortic Arch and Outflow Tract Modifications

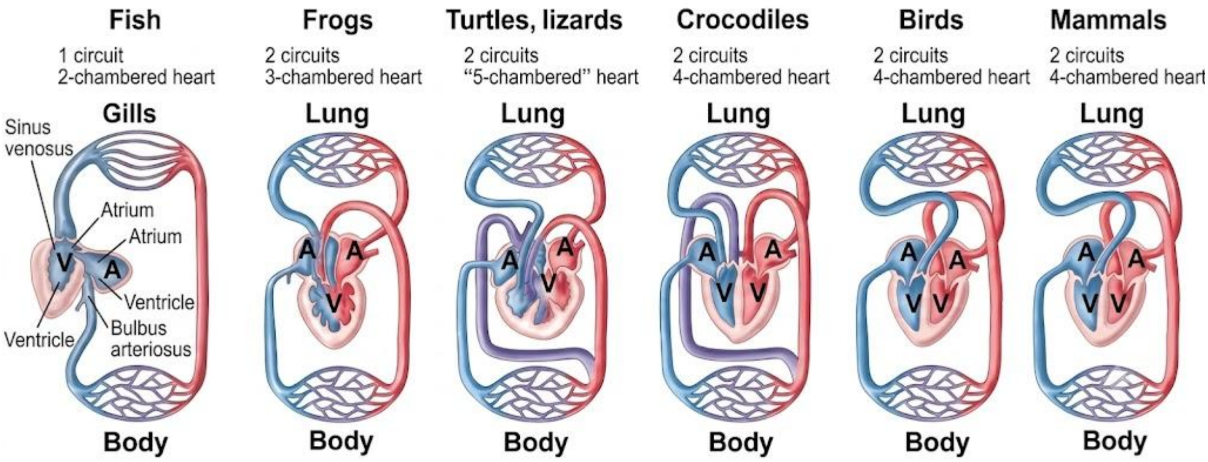
- **Amphibians & Reptiles:** The embryonic conus arteriosus splits into systemic trunks. Reptiles feature a dual systemic arch system (left and right aorta) arising from the ventricle, allowing for cardiac shunting during diving or breath-holding.

- **Birds:** The left systemic arch is completely lost during development; birds possess only a single right systemic arch leading to the dorsal aorta.
- **Mammals:** The right systemic arch is lost during development; mammals possess only a single **left systemic arch** leading to the dorsal aorta.

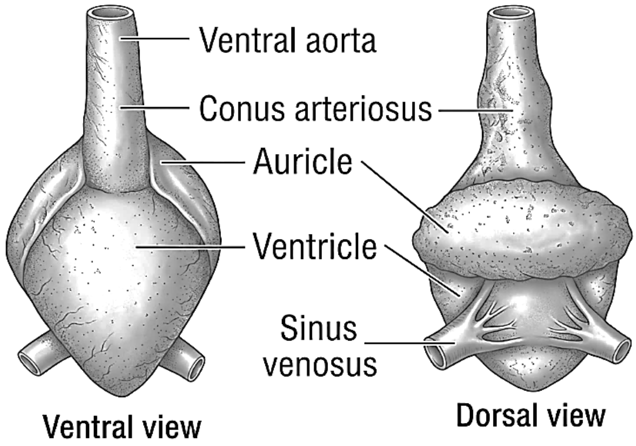
4. Sinus Venosus and Conus Arteriosus Fate

- **Fish & Amphibians:** Both accessory chambers are highly prominent and function as active contractile components of the heartbeat cycle.
- **Reptiles:** The sinus venosus is highly reduced and incorporated almost entirely into the wall of the right atrium.
- **Birds & Mammals:** The sinus venosus completely disappears as a separate chamber, transforming into the sinuatrial (SA) node (the natural pacemaker) within the right atrial wall. The conus arteriosus is absorbed into the bases of the pulmonary artery and aorta.

Evolutionary Trend of the Vertebrate Heart



A. Pisces (e.g., Scoliodon / Shark) – "The Venous Heart."



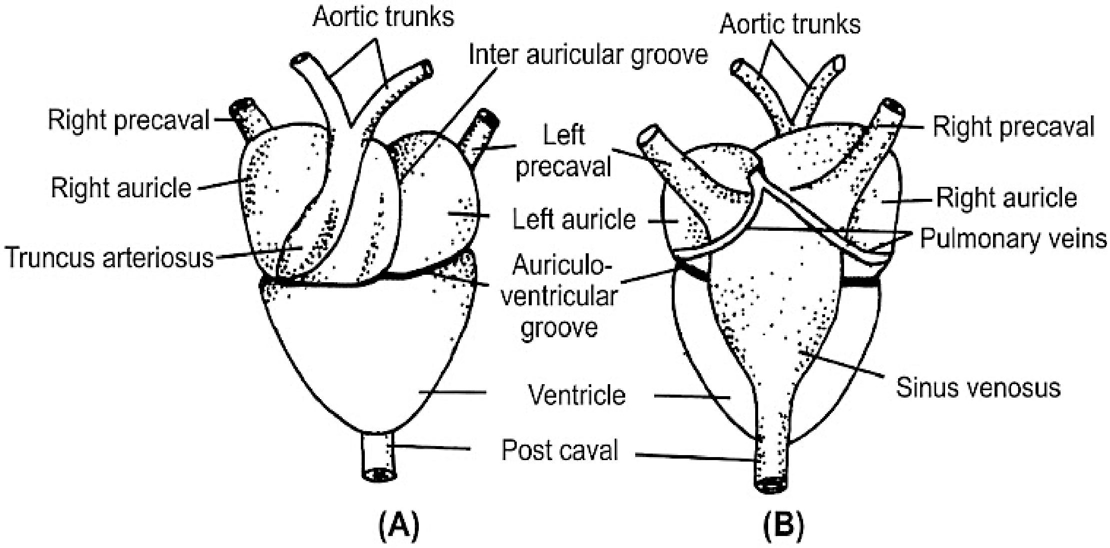
Heart of Scoliodon

Chamber Count: 2 True Chambers (1 Atrium, 1 Ventricle) arranged linearly, accompanied by 2 accessory chambers.

- **Anatomical Structure (Inflow to Outflow)**
  1. **Sinus Venosus:** A thin-walled, triangular accessory chamber that collects deoxygenated blood from the body via the Cuvierian ducts and hepatic sinuses.
  2. **Atrium (Auricle):** A large, triangular, dorsal chamber with muscular walls that receives blood from the sinus venosus via the sinu-atrial aperture.
  3. **Ventricle:** A thick-walled, ventral, pear-shaped muscular chamber that functions as the primary pumping engine.
  4. **Conus Arteriosus:** A thick, muscular, contractile accessory tube extending from the ventricle. Internally, it contains **rows of semi-lunar valves** (usually 3 to 4 rows in *Scoliodon*) to prevent the backflow of blood.
     - *Note on Bony Fishes:* In osteichthyes, the conus is replaced by a non-contractile, elastic Bulbus arteriosus.
- **Circulation Pathway: Single Circuit (Branchial Circulation)**. The heart receives only deoxygenated blood from the body tissues and pumps it directly to the gills for purification. This is why it is called a Venous Heart or Branchial Heart.

Body Tissues→Sinus Venosus→Atrium→Ventricle→Conus→Gills→Body Tissues

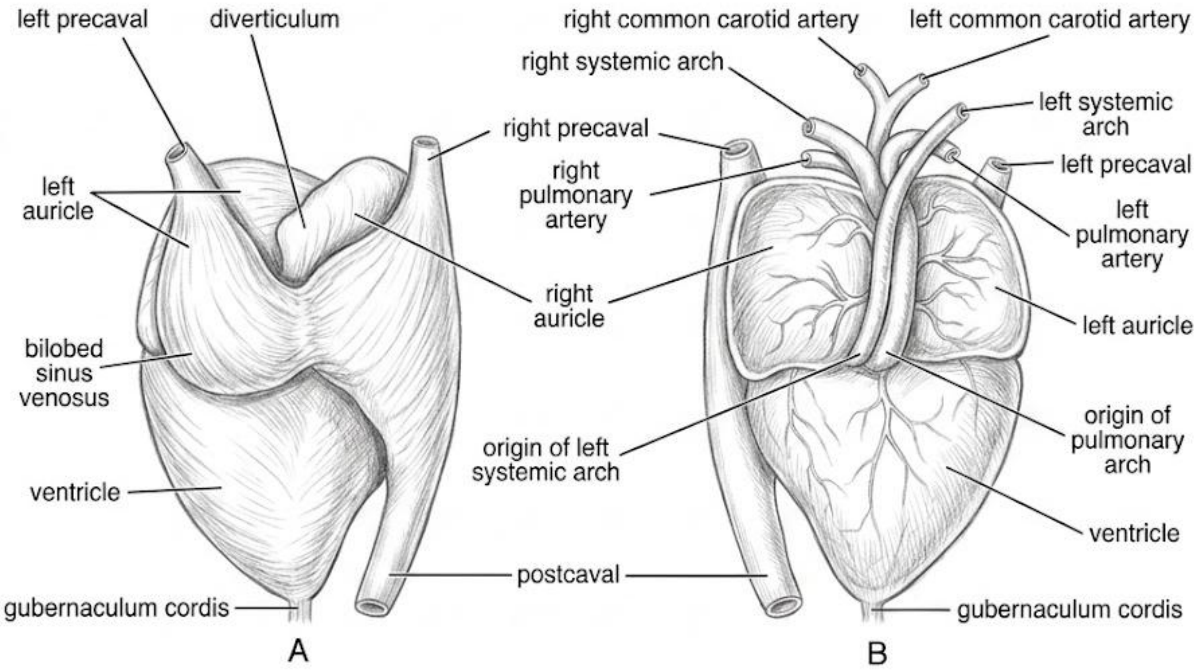
B. Amphibia (e.g., Frog) – "The Transitional 3-Chambered Heart"



Heart of Frog A: Ventral view   B: Dorsal view

- **Chamber Count: 3 Chambers** (2 Atria, 1 Ventricle) with 2 accessory chambers.
- **Anatomical Structure**
  - **Atria:** Completely divided into a **Left Atrium** and a **Right Atrium** by a thin, solid internal wall called the **Inter-atrial septum**. The right atrium is larger and receives deoxygenated blood from the body via the *Sinus Venosus*. The left atrium receives oxygenated blood directly from the lungs/skin via the *Pulmonary veins*.
  - **Ventricle:** A single, thick-walled, conical chamber with internal muscular ridges called **columnae carneae**. It lacks an internal partition wall, meaning both atria empty into this single space.
  - **Truncus Arteriosus:** A single large vessel arising from the ventricle. Internally, it is split by a twisted **spiral valve** that helps direct blood flow into specific arches.
- **Circulation Pathway: Incomplete Double Circulation**. Although oxygenated and deoxygenated blood are separated in the atria, they undergo partial mixing in the single ventricle. However, the internal muscular ridges and the action of the spiral valve in the truncus arteriosus help direct the purest blood toward the carotid arches (head).

C. Reptilia (e.g. Lizard) – "The Incompletely 4-Chambered Heart"

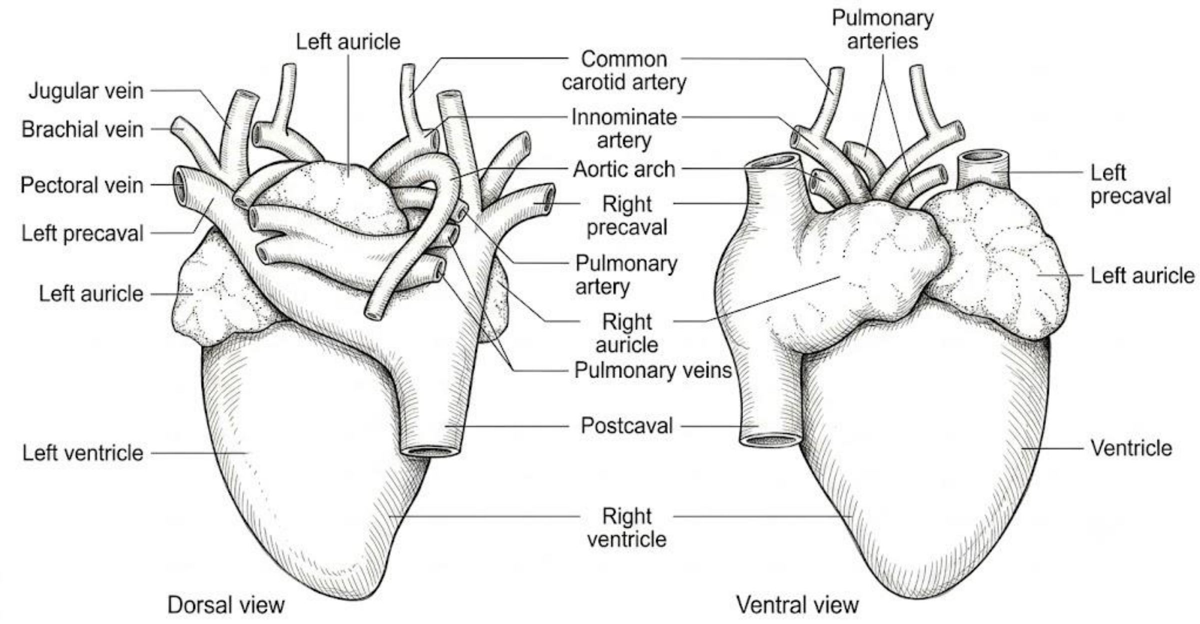


Heart of Lizard A: Dorsal View B: Ventral View

- **Chamber Count: Incompletely 4-Chambered** (2 Atria, 1 Incompletely Divided Ventricle).
- **Anatomical Structure:**
    - **Atria:** Completely separated into right and left chambers. The sinus venosus is reduced in size and integrated mostly into the right atrium.
    - **Ventricle:** The interior of the ventricle is partitioned by an incomplete inter-ventricular septum. This structure divides the ventricular cavity into two functional zones: The *Cavum pulmonale* and the *Cavum venosum*.
    - **Aortic Arches:** The truncus arteriosus is absent. Instead, three independent arches arise directly from the base of the ventricle: the Pulmonary Artery, the Left Systemic Arch, and the Right Systemic Arch.
    - **The Crocodilian Exception:** Crocodiles, Alligators, and Gharials possess a completely 4-chambered heart with a solid inter-ventricular septum. However, blood mixing still occurs outside the heart via a small opening connecting the left and right systemic aortae called the Foramen of Panizza.
- **Circulation Pathway: Incomplete Double Circulation**.

During ventricular contraction, the incomplete septum rises to temporarily seal off the chambers, significantly reducing blood mixing compared to amphibians.

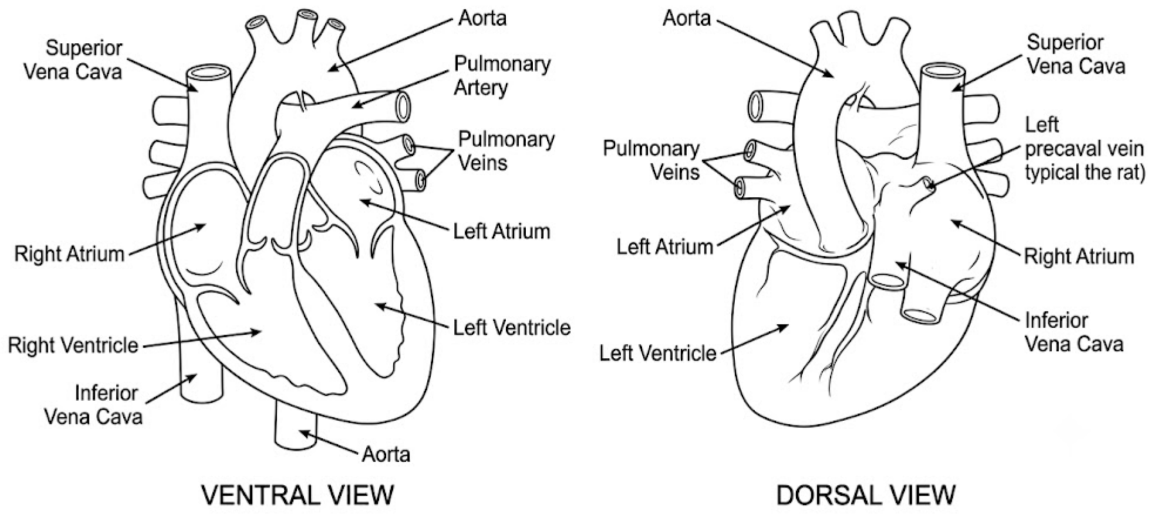
D. Aves (e.g., Pigeon) – "The Complete 4-Chambered Flight Heart"



Heart of Pigeon A: Dorsal View B: Ventral View

- **Chamber Count: 4 Chambers** (2 Atria, 2 Ventricles). Complete separation.
- **Anatomical Structure:**
  - **Atria & Ventricles:** The heart is large, compact, and completely separated into a right and left side by a solid **Inter-atrial septum** and a thick **Inter-ventricular septum**.
  - **Accessory Structures:** The *Sinus venosus* and *Conus/Truncus arteriosus* are completely absent. Deoxygenated systemic veins dump directly into the right atrium.
  - **Aortic Arches:** Only **two large vessels** leave the heart:
  1. From the right ventricle: The **Pulmonary Artery** (carrying deoxygenated blood to the lungs).
  2. From the left ventricle: A single **Right Systemic Arch** (carrying oxygenated blood to the body). *Note: The left systemic arch is completely lost.*
  - **Valves:** The right atrio-ventricular valve is a single, smooth muscular flap, while the left valve is membranous (bicuspid/mitral).
- **Circulation Pathway: Complete Double Circulation**. Absolutely no mixing of oxygenated and deoxygenated blood occurs within the heart, allowing for a high-pressure system to meet the metabolic demands of flight.

E. Mammalia (e.g. Rat) – "The Complete 4-Chambered High-Pressure Heart"



Heart of Rat A: Ventral View B: Dorsal View

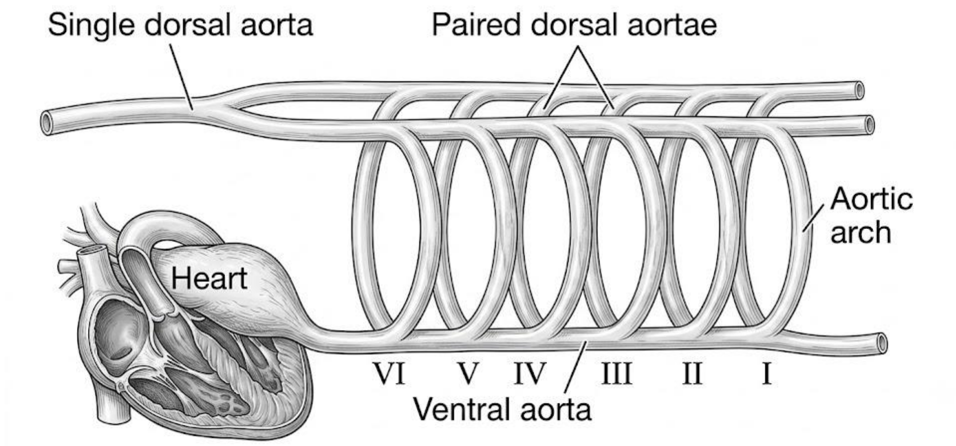
- **Chamber Count: 4 Chambers** (2 Atria, 2 Ventricles). Complete separation.
- **Anatomical Structure:**
  - **Atria & Ventricles:** Completely split into right and left halves. The walls of the left ventricle are three to four times thicker than those of the right ventricle, as it must generate enough pressure to pump blood throughout the systemic loop.
  - **Accessory Structures:** Sinus venosus is completely absent; its remnant forms the **Sinu-atrial (SA) node** (the pacemaker) embedded in the right atrial wall.
  - **Aortic Arches:** Two primary vessels exit the heart:
  1. From the right ventricle: The **Pulmonary Trunk**.
  2. From the left ventricle: A single **Left Systemic Arch** (Aorta) that curves over the left bronchus. *Note: Mammals retain the left arch, whereas birds retain the right arch.*
- **Valves:** Guarded by complex membranous valves supported by fibrous cords (**chordae tendineae**) anchored to muscular pillars (**papillary muscles**).
  - Right AV Valve = **Tricuspid Valve** (three flaps).
  - Left AV Valve = **Bicuspid / Mitral Valve** (two flaps).
- **Circulation Pathway: Complete Double Circulation**.

Right Ventricle →Lungs (Pulmonary Loop) →Left Atrium

Left Ventricle →Body Tissues (Systemic Loop) →Right Atrium

COMPARATIVE STUDY OF AORTIC ARCHES IN VERTEBRATES

The aortic arches are pairs of symmetrically arranged blood vessels that connect the ventral aorta (leaving the heart) to the dorsal aorta (running along the back). In the basic vertebrate embryo, there are 6 pairs of lateral aortic arches, designated by Roman numerals (I to VI), running through the visceral arches.



Basic plan of aortic arches

[Embryonic Archetype: 6 Pairs of Arches]

Ventral Aorta ---> Arches I, II, III, IV, V, VI ---> Dorsal Aorta

The evolutionary history of these arches reflects a transition from aquatic gill respiration to terrestrial lung respiration. As vertebrates moved onto land, the respiratory system shifted from a branchial layout to a pulmonary layout. Consequently, the continuous network of arches was progressively reduced, separated, and specialized to handle independent systemic and pulmonary blood loops.

A. Pisces (e.g., Scoliodon / Shark) – "The Branchial Layout."

Because fish rely entirely on branchial (gill) respiration, their aortic arches remain dedicated to delivering blood to the gills for gas exchange.

- **Embryonic Arches Retained: 4 Pairs** (Arches **III, IV, V, and VI**).
- **Modifications:**
  - **Arch I (Mandibular):** Disappears completely or remains as a rudimentary spiracular artery.
  - **Arch II (Hyoidean):** Lost or modified into an afferent pseudobranchial artery.
  - **Arches III to VI:** Function as true **Branchial Aortic Arches**.
- **Key Structural Detail:** Each functional arch is split into two sections by a capillary bed inside the gill filament:
  1. An **Afferent Branchial Artery** (bringing deoxygenated blood from the ventral aorta to the gills).

2. An **Efferent Branchial Artery** (collecting oxygenated blood from the gills and carrying it to the dorsal aorta).

B. Amphibia (e.g., Frog) – "The Transitional Layout."

With the transition to land, gills are lost in adult amphibians, and respiration shifts to the lungs and skin. Consequently, the continuous gill loops break down, and the arches specialize into major body arteries.

- **Embryonic Arches Retained: 3 Pairs** (Arches **III, IV, and VI**).
- **Modifications:**
  - **Arches I and II:** Disappear completely during early development.
  - **Arch III (Carotid Arch):** Loses its connection to Arch IV. It forms the **Internal and External Carotid Arteries**, which supply oxygenated blood to the head.
  - **Arch IV (Systemic Arch):** Highly developed on both sides. The left and right systemic arches sweep around the pharynx and merge posteriorly to form the single Dorsal Aorta, supplying blood to the rest of the body.
  - **Arch V:** Disappears entirely.
  - **Arch VI (Pulmocutaneous Arch):** Loses its connection to the dorsal aorta (the embryonic *ductus arteriosus* closes). It divides into a Pulmonary Artery (to the lungs) and a Cutaneous Artery (to the skin) for oxygenation.

C. Reptilia (e.g. Lizard) – "The Triple-Trunk Layout"

Reptiles have a completely terrestrial lifestyle with exclusive lung respiration. To handle this, the embryonic *truncus arteriosus* splits cleanly down to its base into **three independent structural vessels** (trunks).

- **Embryonic Arches Retained: 3 Pairs** (Arches **III, IV, and VI**).
- **Modifications:**
  - **Arch III (Carotid Arch):** Arises directly from the right systemic arch. It supplies the head via the carotid arteries.
  - **Arch IV (Systemic Arches):** Retained on both sides (Left and Right). However, they arise from different parts of the partially divided ventricle:
  - The Right Systemic Arch originates from the left side of the ventricle (carrying purer oxygenated blood).
  - The Left Systemic Arch originates from the right side of the ventricle (carrying mixed blood).

- These two arches cross over each other as they exit the heart and merge behind it into the dorsal aorta.
- **Arch V:** Completely absent.
- **Arch VI (Pulmonary Arch):** Arises as a completely separate vessel from the right side of the ventricle (*cavum pulmonale*). It splits into left and right pulmonary arteries to supply the lungs with deoxygenated blood.

D. Aves (e.g., Pigeon) – "The Right Systemic Layout"

Birds require a highly efficient, high-pressure circulatory system to sustain flight. To eliminate the structural clutter that can lead to blood mixing, they eliminate one side of the systemic loop.

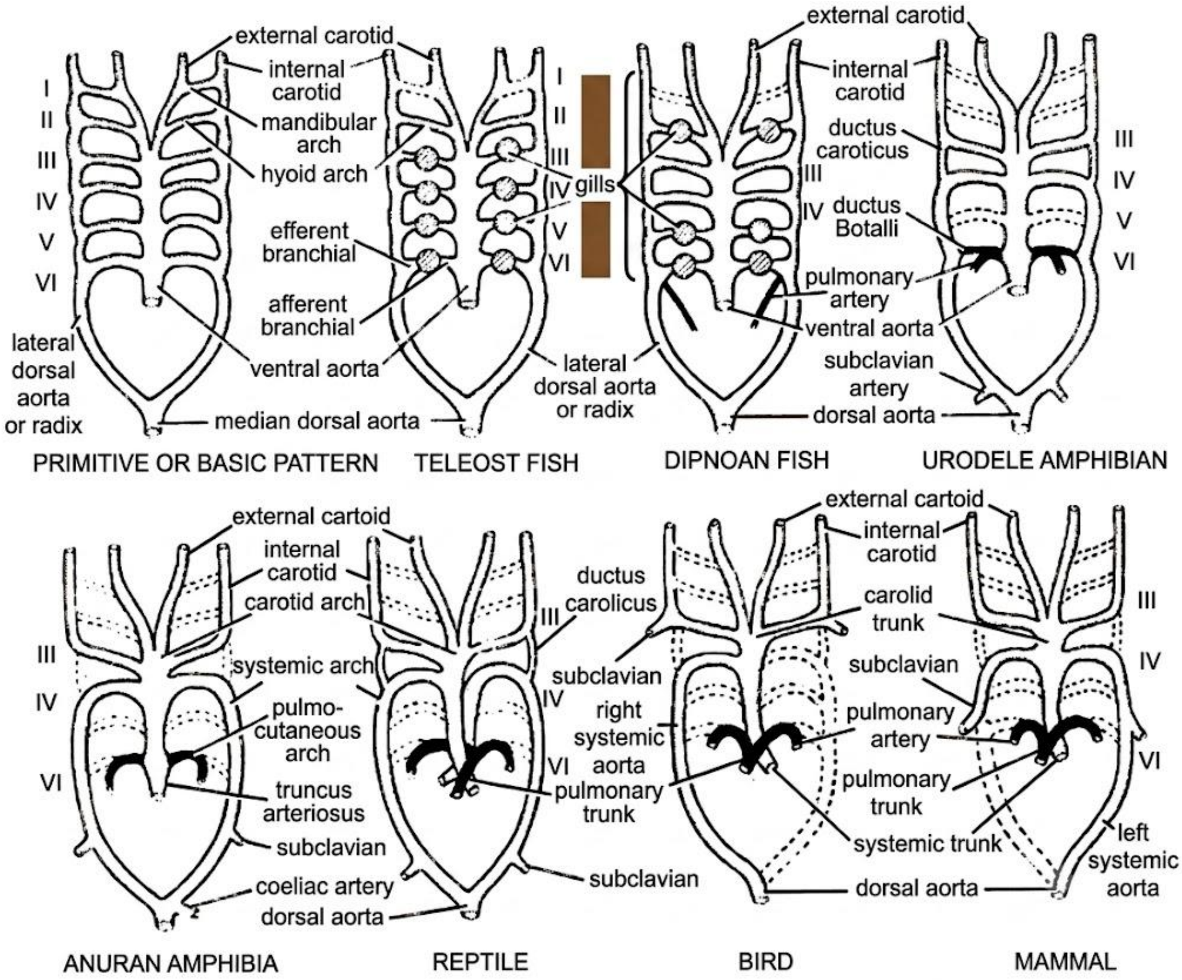
- **Embryonic Arches Retained: 3 Pairs** (Arches **III, IV, and VI,** but Arch IV becomes asymmetrical).
- **Modifications:**
  - **Arch III (Carotid Arch):** Forms the prominent carotid system supplying blood to the brain.
  - **Arch IV (Systemic Arch):** Retained only on the Right Side. The embryonic left fourth arch disappears completely during development. The Right Systemic Arch emerges from the left ventricle, loops over the right bronchus, and continues backward as the dorsal aorta.
  - **Arch V:** Absent.
  - **Arch VI (Pulmonary Arch):** Emerges from the right ventricle and splits into the left and right pulmonary arteries to supply the lungs.

E. Mammalia (e.g. Rat) – "The Left Systemic Layout"

Like birds, mammals have achieved a complete separation of oxygenated and deoxygenated blood. However, they arrived at this evolutionary milestone by retaining the opposite side of the systemic loop.

- **Embryonic Arches Retained: 3 Pairs** (Arches III, IV, and VI, with Arch IV asymmetrical).
- **Modifications:**
  - **Arch III (Carotid Arch):** Forms the common carotid system.
  - **Arch IV (Systemic Arch):** Retained only on the Left Side. The embryonic right fourth arch disappears, except for its proximal portion which forms the right subclavian artery. The functional Left Systemic Arch (Aorta) emerges from the left ventricle, loops over the left bronchus, and runs backward as the dorsal aorta.

- **Arch V:** Disappears entirely during embryogenesis.
- **Arch VI (Pulmonary Arch):** Emerges from the right ventricle as the pulmonary trunk, supplying the lungs. *Note: In the mammalian fetus, the connection between Arch VI and the left systemic arch remains open as the Ductus arteriosus. At birth, this closes and hardens into a solid fibrous cord, the Ligamentum arteriosum.*



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COMPARATIVE STUDY OF BRAIN OF VERTEBRATES

The vertebrate brain exhibits a distinct evolutionary trajectory, progressing from a primitive, linear structure in lower vertebrates to a highly cephalized, convoluted organ in higher mammals. This practical study compares representative brains across Pisces, Amphibia, Reptilia, Aves, and Mammalia to analyze how ecological adaptations have shaped specific encephalic regions.

1. The Forebrain (Prosencephalon)

This is the largest and most advanced part of the brain. It handles thoughts, senses, and emotions.

- **Cerebrum:** The biggest part of the brain.
  - *Function:* It controls your thinking, memory, learning, and emotions. It is also what allows you to see, hear, taste, touch, and choose to move your muscles.
- **Thalamus:** The brain's switching center.
  - *Function:* It acts like a post office. It takes sensory information (like what you see or hear) and sends it to the right part of the cerebrum.
- **Hypothalamus:** The body's thermostat and control panel.
  - *Function:* It keeps your body in balance. It controls hunger, thirst, sleep, body temperature, and emotions.

2. The Midbrain (Mesencephalon)

This is a small but important bridge in the middle of the brain.

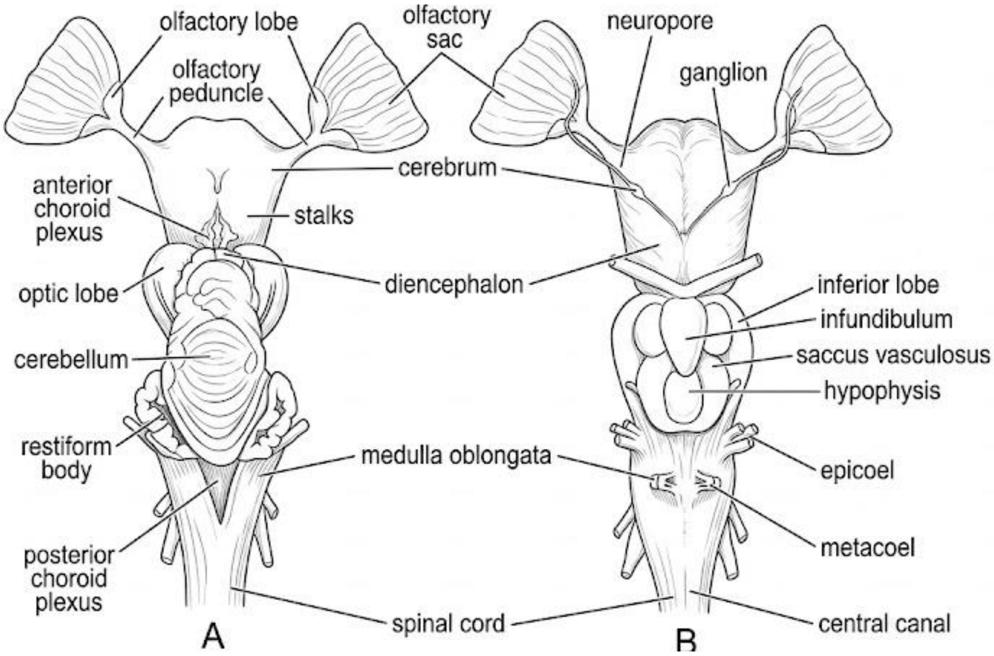
- **Optic/Auditory Lobes:** * *Function:* It handles quick reflexes related to seeing and hearing. For example, if a loud noise happens, the midbrain makes you automatically turn your head toward it. It also helps pass sensory information up to the forebrain.

3. The Hindbrain (Rhombencephalon)

Located at the back and bottom of the brain, this part handles automatic survival functions and physical coordination.

- **Cerebellum:** Often called the "little brain."
  - *Function:* It coordinates your balance and movement. It helps you walk smoothly, ride a bicycle, or catch a ball without falling over.
- **Medulla Oblongata:** The automatic control center.
  - *Function:* It keeps you alive by controlling things you don't have to think about, like your heartbeat, breathing, blood pressure, and swallowing.
- **Pons:** The bridge.
  - *Function:* It connects different parts of the brain together and helps regulate sleep and breathing.

A. Pisces (e.g., Scoliodon / Shark) – "The Olfactory Brain"

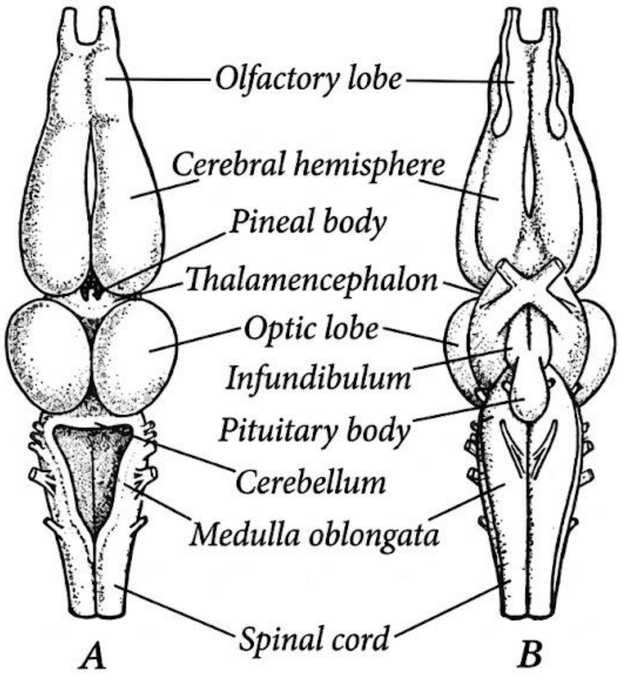


Brain of Scolioon A: Dorsal View B: ventral View

Because fish rely heavily on chemical cues to navigate their aquatic environment, the brain is highly adapted for processing smells.

- **Forebrain:** Features exceptionally large, prominent **Olfactory Lobes** connected to the anterior olfactory bulbs. The **Cerebrum** (cerebral hemispheres) is relatively small, undivided, and functions primarily as an olfactory processing center rather than an intelligence hub.
- **Midbrain:** Consists of a pair of large, smooth **Optic Lobes** processing visual data.
- **Hindbrain:** The **Cerebellum** is large, elongated, and folds backward over the medulla. This expansion is critical for maintaining equilibrium, spatial orientation, and swimming balance in a 3D fluid environment. The **Medulla Oblongata** is well-developed, featuring prominent lateral expansions called **Restiform bodies** (auricles of the cerebellum) unique to cartilaginous fish.

B. Amphibia (e.g., Frog) – "The Primitive & Sluggish Brain"

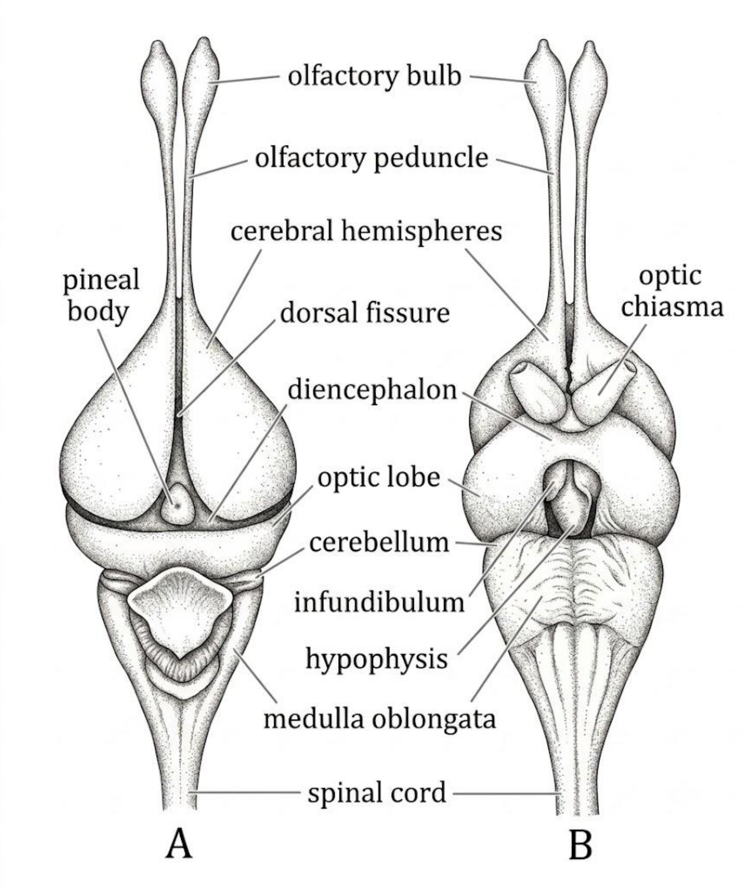


Brain of Frog A: Dorsal View B: ventral View

Amphibians exhibit a simple, unspecialized brain layout that reflects a transition to land without complex behavioral or athletic adaptations.

- **Forebrain:** The **Olfactory Lobes** are large but completely fused along the midline. The **Cerebrum** is distinct and divided into two elongated **Cerebral Hemispheres** by a deep longitudinal fissure. However, its surface is smooth and lacks gray matter (*neopallium*).
- **Midbrain:** Features a pair of large, oval **Optic Lobes** (Corpora bigemina), which function as the primary coordination center for the entire nervous system.
- **Hindbrain:** The **Cerebellum** is reduced to a thin, narrow, transverse ribbon of tissue just behind the optic lobes. This minimal development reflects the frog's relatively simple, restricted range of locomotor activities. The **Medulla Oblongata** is standard and tapers directly into the spinal cord.

C. Reptilia (e.g. Lizard) – "The Intermediate Brain"

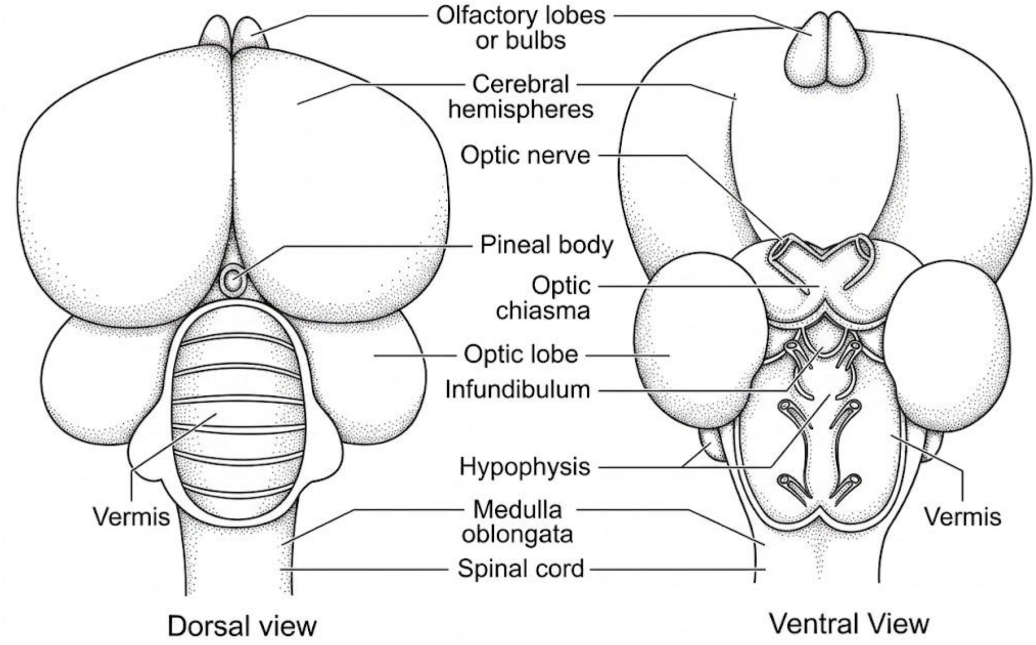


Brain of Lizard A: Dorsal View B: ventral View

Reptilian brains display clear structural advancements to support complex terrestrial locomotion, predation, and sensory awareness.

- **Forebrain:** The **Cerebral Hemispheres** are significantly larger, wider, and extend backward to partially cover the diencephalon. For the first time, a primitive layer of gray matter (**Neopallium/Cerebral Cortex**) appears on the surface, supporting more flexible behavioral choices. The diencephalon features a prominent **Parietal/Pineal Eye** (photoreceptive organ) on its roof.
- **Midbrain:** Prominent, rounded **Optic Lobes** that are pushed slightly sideways due to the expansion of the forebrain.
- **Hindbrain:** The **Cerebellum** is a distinct, pear-shaped, upward-projecting dome. It is much larger than the amphibian ribbon, supporting agile terrestrial movements like climbing, running, and hunting.

D. Aves (e.g., Pigeon) – "The Flight Coordination Brain"

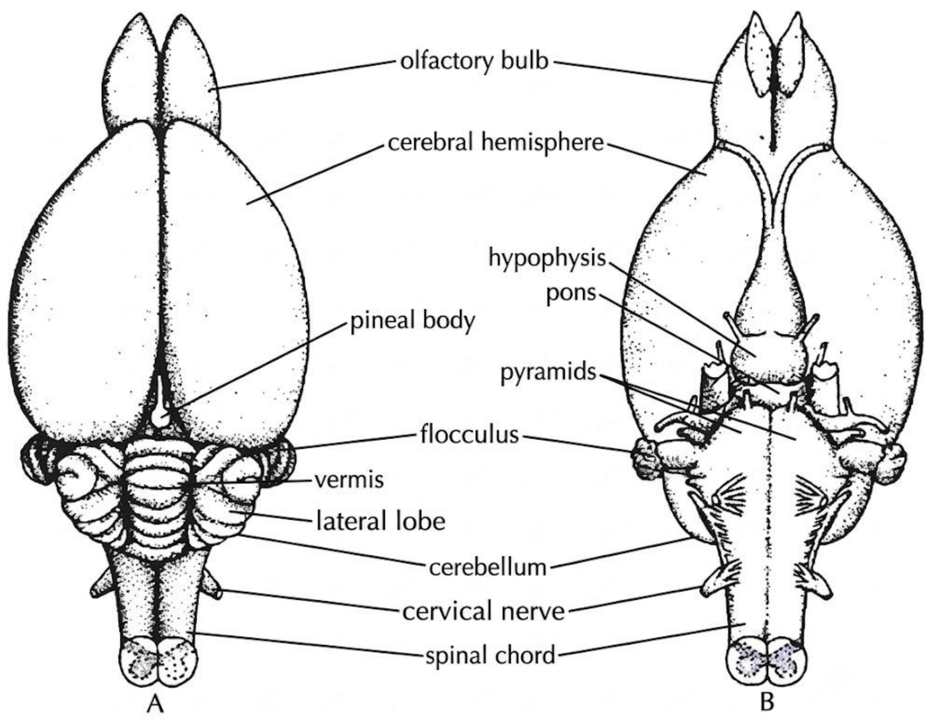


Brain of Pigeon A: Dorsal View B: ventral View

The avian brain is large, compact, and specialized to handle the high-speed spatial navigation and muscle coordination required for flight.

- **Forebrain:** The **Cerebral Hemispheres** are massive, smooth, rounded domes that push backward to completely hide the diencephalon. While the outer surface is smooth (lacks folds), the internal base contains a highly developed mass called the **Corpus Striatum** (Hyperstriatum), which manages complex, instinctive flight behaviors and migration.
- **Midbrain:** The **Optic Lobes** are exceptionally large and shifted laterally down to a ventrolateral position because the massive cerebrum and cerebellum push them aside.
- **Hindbrain:** The **Cerebellum** is massive and highly advanced. It is divided into a large central **Vermis** and two small lateral **Flocculi**. Its surface is heavily folded into narrow ridges (**Gyri and Sulci**) to maximize surface area, enabling the rapid motor computations needed for flight stability.

E. Mammalia (e.g. Rat) – "The Intelligent Convolution Brain"



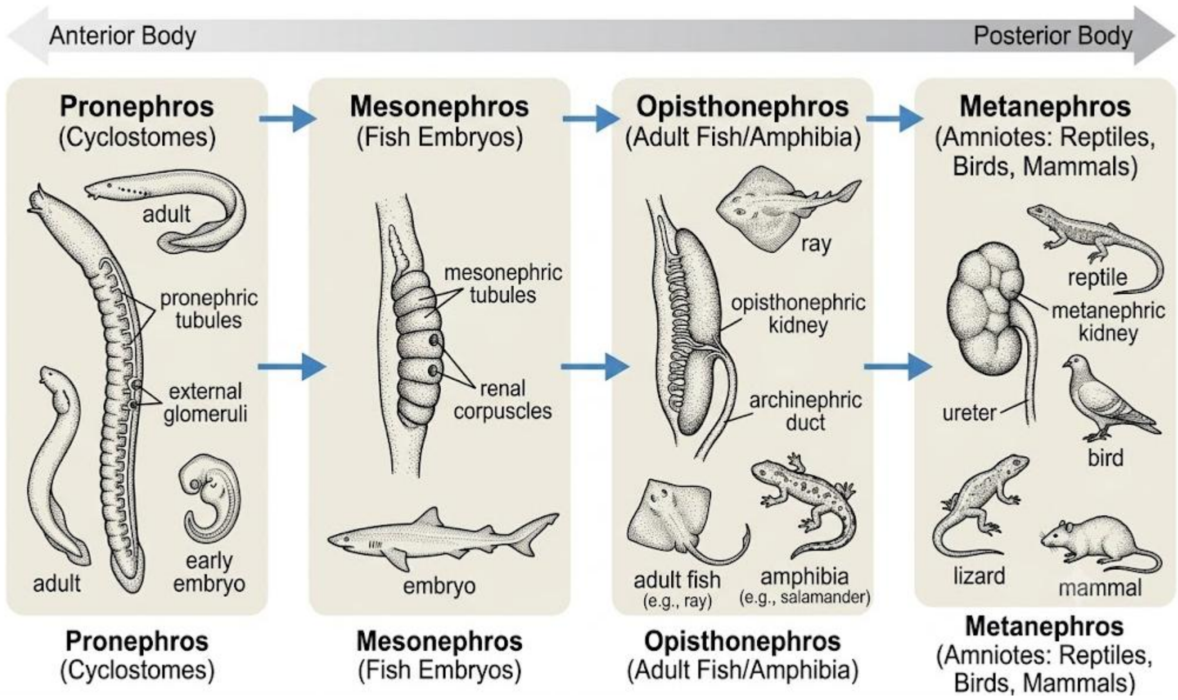
Brain of Rat A: Dorsal View B: ventral View

The mammalian brain is defined by a massive expansion of the cerebral cortex, supporting unparalleled intelligence, memory, and voluntary motor control.

- **Forebrain:** The **Cerebral Hemispheres** are massive, dominating the entire brain architecture and covering the midbrain. The outer layer (**Neocortex**) is deeply folded into grooves (*sulci*) and ridges (*gyri*), maximizing the surface area of processing neurons. The left and right hemispheres are structurally linked by a thick, horizontal band of nerve fibers called the **Corpus Callosum** (found only in placental mammals).
- **Midbrain:** The midbrain is completely hidden beneath the cerebrum. It is uniquely divided into **four lobes** rather than two, forming the **Corpora Quadrigemina** (the upper pair processes vision, while the lower pair handles auditory reflexes).
- **Hindbrain:** The **Cerebellum** is large, highly complex, and divided into a central *vermis* and two large *lateral hemispheres*. Additionally, a thick bridge of transverse nerve fibers called the **Pons Varolii** develops on the ventral side of the medulla to coordinate signals between the cerebral cortex and the cerebellum.

COMPARATIVE STUDY OF VERTEBRATE KIDNEY

The vertebrate kidney is an excretory and osmoregulatory organ derived from the embryonic mesoderm (specifically the nephrotome plate lying along the length of the coelom). The structural evolution of the kidney exhibits a clear trend: progressive shifting of the functional zone from the anterior to the posterior region of the body, accompanied by an immense increase in the complexity and efficiency of individual filtering units called nephrons. According to evolutionary and embryological evidence, the vertebrate kidney transitions through four distinct structural layouts.

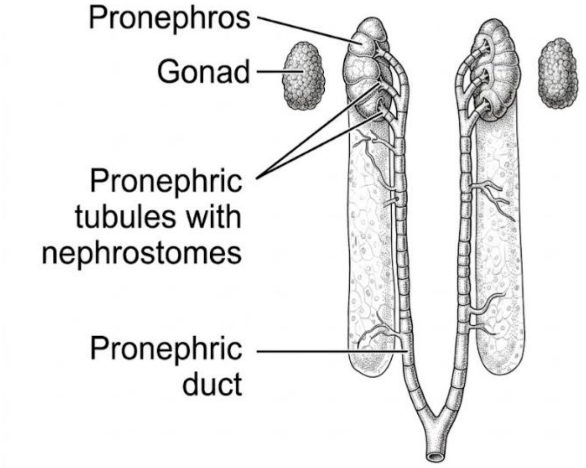


Evolutionary timeline of the vertebrate kidney

The evolutionary timeline of the vertebrate kidney transitions from the anterior to the posterior body region, increasing in complexity.

- **Pronephros**: Found in primitive cyclostomes, this basic kidney develops at the far anterior section of the body.
- **Mesonephros**: Replaces the pronephros functionally during the embryonic stages of fish and amphibians.
- **Opisthonephros**: The functional adult kidney of most fish and amphibians, extending further along the posterior body.
- **Metanephros**: The most advanced, highly concentrated kidney located in the strict posterior region, serving adult amniotes like reptiles, birds, and mammals.

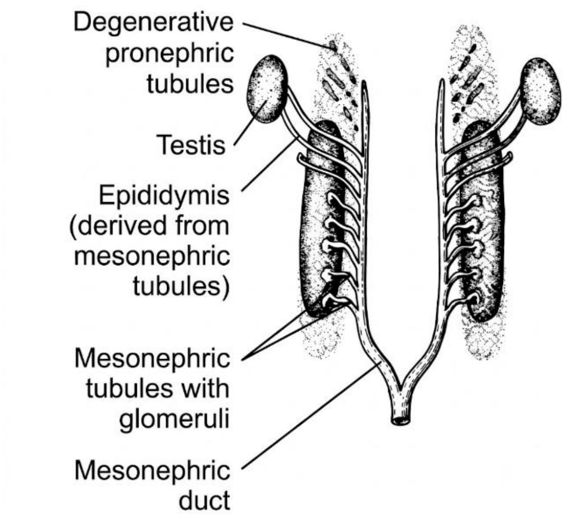
A. Pronephros (The Head Kidney)



Pronephric Kidney

- **Evolutionary Position:** The most primitive, ancestral kidney type.
- **Location:** Located at the far anterior (head) region of the body.
- **Structure:** It consists of a very limited number of segmental tubules (usually 3 to 5 pairs).
  - The tubule opens directly into the body cavity (coelom) via a ciliated funnel called the **nephrostome**.
  - It filters waste from the coelomic fluid rather than directly from blood vessels. The blood vessels form a loose cluster called an external **glomus** near the funnel.
  - All tubules drain into a shared longitudinal duct called the **Pronephric duct**.
- **Occurrence:** Functional only in adult **Cyclostomes** (like hagfishes) and the embryos/larvae of primitive fishes and amphibians. In all other vertebrates, it disappears early during embryonic development.

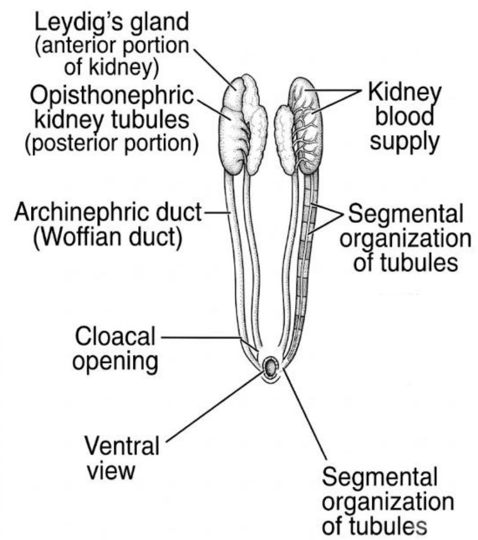
B. Mesonephros (The Wolffian Kidney)



Mesonephric Kidney

- **Evolutionary Position:** The intermediate transitional stage.
- **Location:** Located in the middle segment of the body cavity, directly behind the degenerated pronephros zone.
- **Structure:** The tubules multiply in number and lose their open connection to the body coelom.
  - The ciliated funnels (nephrostomes) close up and disappear.
  - Instead, each tubule forms a double-walled cup called **Bowman's capsule**, which wraps around an internal knot of capillaries called a **glomerulus** to form a **Malpighian corpuscle**. This enables the direct filtration of blood.
  - These tubules tap into the pre-existing pronephric duct, which is renamed the **Mesonephric duct (or Wolffian duct)**.
- **Occurrence:** Functional during the embryonic stages of all fishes, amphibians, reptiles, birds, and mammals.

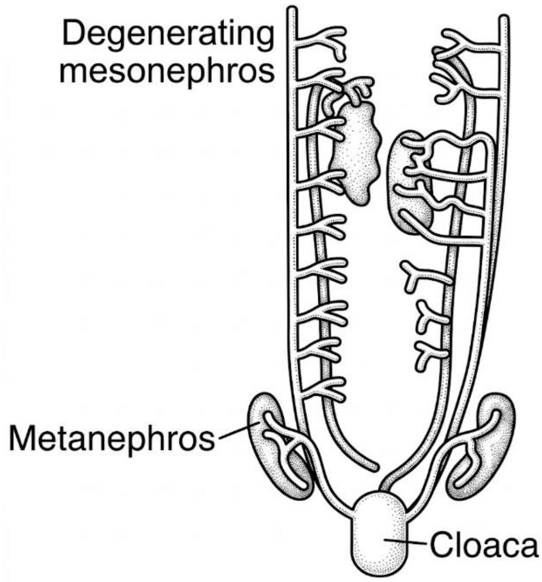
C. Opisthonephros (The Adult Anamniote Kidney)



Opisthonephric Kidney

- **Evolutionary Position:** An advanced modification of the middle kidney layout.
- **Location:** Extends along the entire posterior half of the body.
- **Structure:** It forms when the embryonic mesonephros grows backward to incorporate the remaining posterior nephrotome tissue.
  - The anterior part may specialize for reproduction (e.g., in male sharks, it forms the epididymis), while the extensive posterior section functions as the main urinary engine.
  - It utilizes the **Wolffian duct** to transport urine. In males, this duct pulls double duty, serving as both a vas deferens for sperm and a ureter for urine.
- **Occurrence:** The standard adult kidney is found in all **Fishes (Pisces)** and **Amphibians**.

D. Metanephros (The True Land Kidney)



Metanephric Kidney

- **Evolutionary Position:** The most advanced, highly specialized kidney layout.
- **Location:** Located in the extreme posterior pelvic region of the body cavity.
- **Structure:** Completely isolated from the reproductive system.
  - The kidney originates from two distinct parts: a backward growth called the **metanephric diverticulum** (which forms a brand-new, dedicated urinary pipeline called the **Ureter**) and a posterior block of tissue that develops millions of highly intricate nephrons.
  - Each nephron is highly elongated and differentiated into specialized zones for targeted water and salt retention (e.g., the **Loop of Henle** in mammals).
- **Occurrence:** The standard adult kidney of all **Amniotes (Reptiles, Birds, and Mammals)**.

Class-Wise Adaptations and Excretory Profiles

1. Pisces

- **Anatomy:** Long, narrow, dark red bands running along the roof of the coelom.
- **Excretory Profile: Ureotelic** (sharks conserve urea in their blood to remain osmotically balanced with seawater) or **Ammonotelic** (bony fishes flush dilute ammonia directly into the water).

2. Amphibia

- **Anatomy:** A pair of compact, flattened, oval, deep-red bodies located on either side of the vertebral column. A distinct golden adrenal gland runs along its ventral surface.

- **Excretory Profile: Ureotelic** on land (excreting urea to save water) but **Ammonotelic** during the aquatic tadpole stage.

3. Reptilia

- **Anatomy:** Small, lobed, and shifted deep into the pelvic cavity. Left and right kidneys are frequently fused at their posterior ends.
- **Excretory Profile: Uricotelic**. Excretes nitrogenous waste as a dry, semi-solid paste of **uric acid** crystals to maximize water conservation in dry terrestrial habitats.

4. Aves

- **Anatomy:** Large, dark-brown, three-lobed structures (Anterior, Middle, and Posterior lobes) fitted neatly into the hollow recesses of the pelvis (*synsacrum*).
- **Excretory Profile: Uricotelic**. Like reptiles, birds excrete uric acid paste. To minimize weight for flight, a **urinary bladder is completely absent** (except in ostriches); urine is evacuated instantly.

5. Mammalia

- **Anatomy:** Bean-shaped, compact, smooth, dark-red organs. Internally, it is clearly differentiated into an outer **Cortex** (containing Malpighian corpuscles) and an inner **Medulla** (containing the Loops of Henle and collecting ducts).
- **Excretory Profile: Ureotelic**. The nephrons feature highly elongated **Loops of Henle** that create a concentration gradient, allowing mammals to produce highly concentrated urine to conserve body water.

TYPES OF VERTEBRAE BASED ON THE CENTRUM

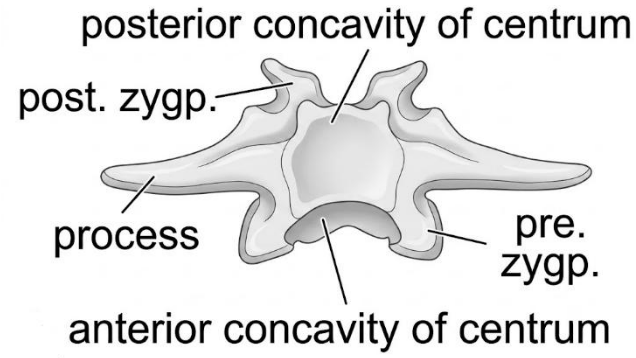
The vertebra is the fundamental structural unit of the vertebral column. It typically consists of a dorsal neural arch (enclosing the spinal cord) and a ventral, solid bony block called the centrum. The centrum replaces the embryonic notochord during development. The shape and contour of the anterior and posterior articulating faces of the centrum determine how individual vertebrae articulate with one another. This structural variation directly dictates the degree of flexibility, strength, and mobility of the backbone across different vertebrate groups.

Classification of Vertebrae Based on the Centrum

There are six major anatomical types of vertebrae recognized based on the shape of their centrum faces.

1. Procoelous: Anterior concave, Posterior convex
2. Opisthocoelous: Anterior convex, Posterior concave
3. Amphicoelous: Both ends concave
4. Amphiplatyan: Both ends flat
5. Heterocoelous: Saddle-shaped articulating ends
6. Acoelous: Flat, lacking deep depressions

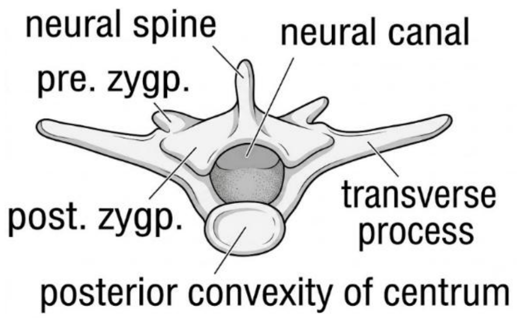
1. Amphicoelous Vertebrae



8th vertebra of frog

- **Anatomical Structure:** Both the anterior and posterior faces of the centrum are deeply **concave** (hollowed inward).
- **Key Feature:** The space between adjacent centra contains a persistent remnant of the gelatinous **notochord**, which acts as a shock absorber.
- **Functional Mobility:** Allows simple, continuous lateral undulatory movements but offers limited vertical support.
- **Occurrence:** Found in **Fishes** (e.g., *Scoliodon*, bony fishes) and primitive reptiles like *Sphenodon* (Tuatara).

2. Procoelous Vertebrae



- **Anatomical Structure:** The anterior face of the centrum is **concave** (hollowed), while the posterior face is **convex** (bulging outward).
- **Key Feature:** The convex posterior face of one vertebra fits like a ball into the concave anterior socket of the succeeding vertebra, forming a secure **ball-and-socket joint**.
- **Functional Mobility:** Provides excellent flexibility and prevents dislocation during movement on land.
- **Occurrence:** Standard layout in most modern amphibians (**Anura / Frogs**) and the majority of modern reptiles (**Lizards and Snakes**).

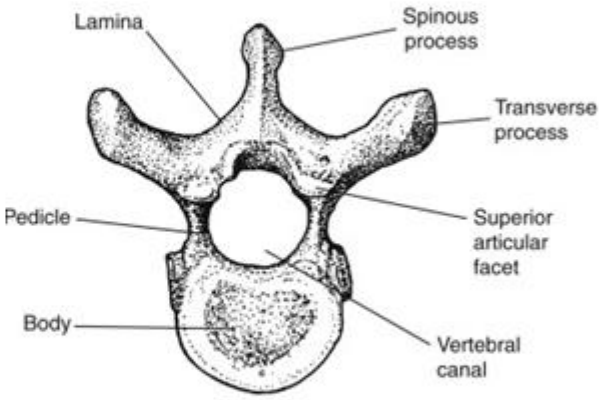
3. Opisthocoelous Vertebrae

- **Anatomical Structure:** The exact reverse of procoelous. The anterior face of the centrum is **convex**, while the posterior face is **concave**.
- **Key Feature:** Forms a ball-and-socket joint where the ball faces forward.
- **Functional Mobility:** Provides high load-bearing structural strength while maintaining structural flexibility.
- **Occurrence:** Found in tailed amphibians (**Urodela / Salamanders**) and the cervical (neck) vertebrae of many large herbivorous dinosaurs and some large mammals.

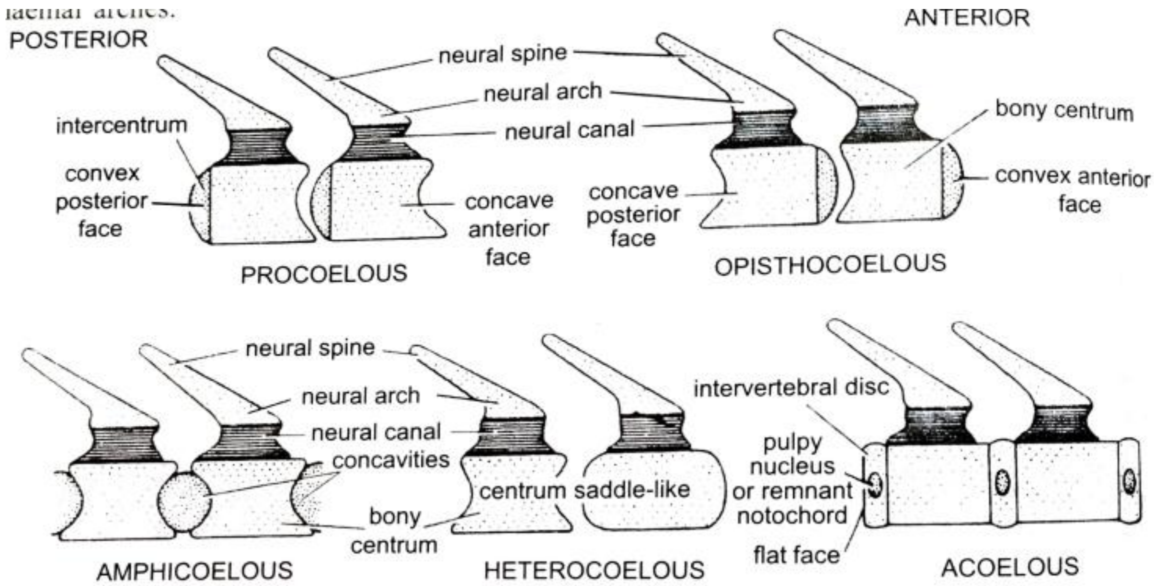
4. Heterocoelous Vertebrae (Saddle-Shaped)

- **Anatomical Structure:** The articulating surfaces are **saddle-shaped**. One face is concave from side-to-side and convex from top-to-bottom, while the matching face is reversed.
- **Key Feature:** This complex interlocking system prevents rotation or twisting along the long axis while permitting maximum lateral and vertical bending.
- **Functional Mobility:** Provides the extreme neck flexibility required by birds for preening, hunting, and turning their heads up to **180°C** or more without straining the spinal cord.
- **Occurrence:** Exclusively characteristic of **Birds (Aves)**, particularly prominent in the long cervical (neck) vertebrae.

5. Amphiplatyan / Acoelous Vertebrae



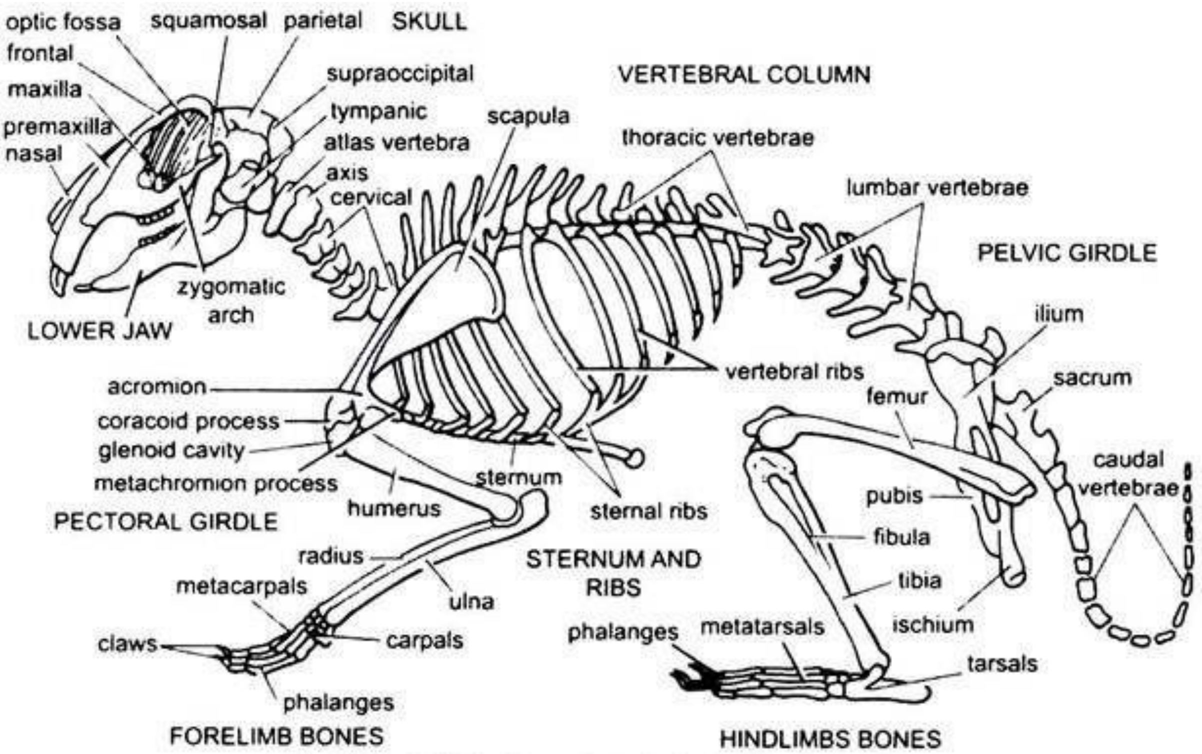
- **Anatomical Structure:** Both the anterior and posterior faces of the centrum are completely **flat** or nearly flat.
- **Key Feature:** The centra do not interlock directly. Instead, they are separated by a flat, cushioning disc of fibrocartilage called an **intervertebral disc** (derived from the embryonic notochord).
- **Functional Mobility:** Designed for maximum compression resistance, stability, and weight-bearing support, sacrificing extreme flexible wriggling for upright strength.
- **Occurrence:** Characteristic of **Mammals (Mammalia)**.



Types of vertebrae on the shape of centra in sagittal section

VERTEBRAL COLUMN OF THE RABBIT

The mammalian vertebral column shows a high degree of regional specialization (differentiation) compared to lower vertebrates. Instead of a uniform sequence of bones, the backbone is divided into five distinct regions tailored for terrestrial locomotion, weight-bearing, and head mobility. The total number of vertebrae is relatively constant within species. The regional distribution is expressed via a standard formula.

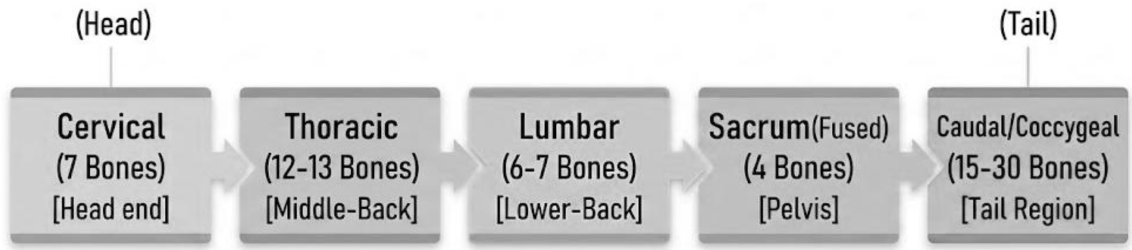


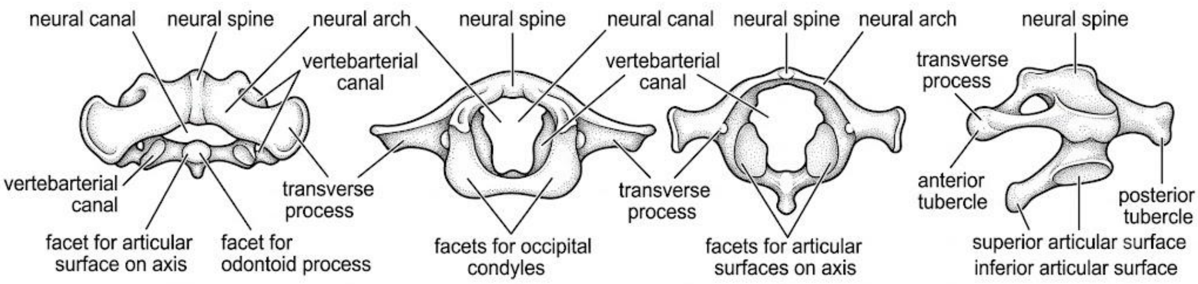
Rabbit (*Oryctolagus*)

Important Mammalian Rule: Almost all mammals, from the short-necked rat and rabbit to the long-necked Giraffe, possess exactly 7 Cervical Vertebrae.

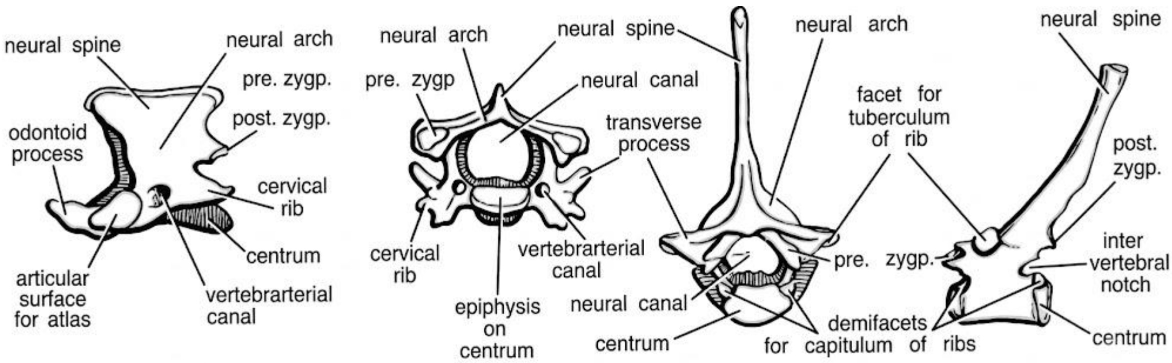
2. Regional Anatomical Analysis

Regional Divisions of the Mammalian Vertebral Column





1. ATLAS: DORSAL VIEW **2. ATLAS: ANTERIOR VIEW** **3. ATLAS: POSTERIOR VIEW** **4. ATLAS: LATERAL VIEW**

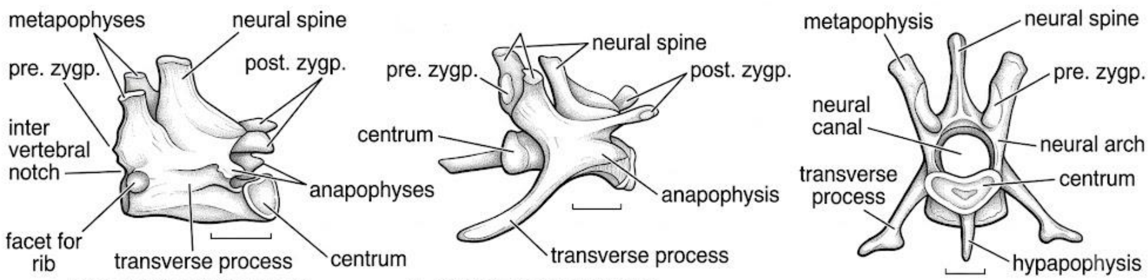


4. AXIS (*Lateral view*)

5. TYPICAL CERVICAL (*Anterior view*)

6. ANTERIOR THORACIC (*Anterior view*)

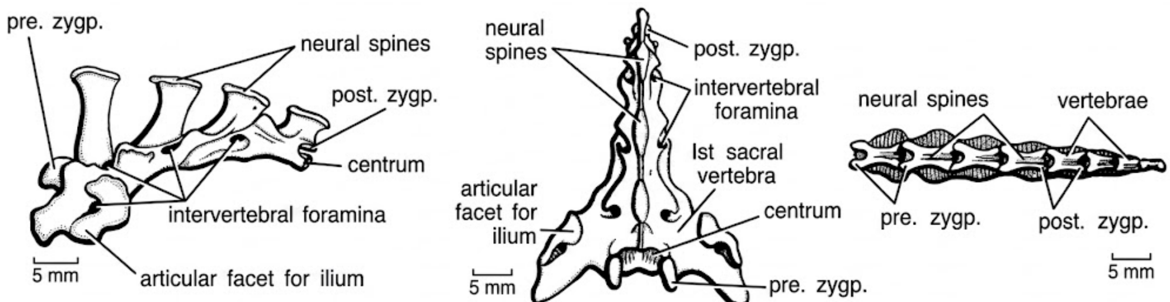
7. ANTERIOR THORACIC (*Lateral view*)



8. POSTERIOR THORACIC (*Lateral view*)

10. POSTERIOR LUMBAR (*Lateral view*)

9. ANTERIOR LUMBAR (*Anterior view*)



11. SACRUM (*Lateral view*)

12. SACRUM (*Dorsal view*)

13. CAUDAL (*Dorsal view*)

A. Cervical Vertebrae (Neck Region Always 7)

The first two cervical vertebrae are highly modified to facilitate complex movements of the head.

1. **First Cervical (Atlas)**
   - **Structure:** Ring-like and completely lacks a centrum and a true neural spine. It features large, wing-like lateral transverse processes.
   - **Identification Feature:** Possesses deep anterior concave articular facets that pair with the occipital condyles of the skull, forming a hinge joint responsible for vertical nodding ("Yes" movement).
2. **Second Cervical (Axis)**
   - **Structure:** Features a prominent, peg-like projection called the Odontoid process arising from the anterior face of its centrum.
   - **Identification Feature:** The odontoid peg inserts directly into the floor ring of the Atlas, acting as a pivot joint responsible for rotational shaking ("No" movement).
3. **Typical Cervical (3rd to 7th)**
   - **Structure:** Centra are flat (**Acoelous/Amphiplatyan**).
   - **Identification Feature:** Each transverse process is perforated at its base by a distinct canal called the Vertebrarterial canal (foramina transversaria), which protects the passage of the vertebral artery to the brain.

B. Thoracic Vertebrae (Chest Region 12 to 13)

This region is specialized to support the rib cage and protect the thoracic organs (heart and lungs).

- **Structure:** Centra are short and robust. The Neural Spines are exceptionally long, slender, and directed backward to serve as attachment points for heavy neck and back muscles.
- **Identification Feature:** Look for smooth, small cartilage seats called costal facets (demifacets) located on the sides of the centra and transverse processes. These facets form joints with the heads (capitulum and tuberculum) of the ribs.

C. Lumbar Vertebrae (Loin/Lower Back Region 6 to 7)

The lumbar vertebrae are the largest, heaviest, and most muscularly reinforced individual bones in the column, as they bear the weight of the trunk.

- **Structure:** The centra are thick and broad. The neural spines are short, flat, and directed forward.
- **Identification Feature:** Characterized by the presence of prominent, forward-pointing, wing-like lateral extensions called Metapophyses and downward-pointing

Anapophyses flanking the neural arch, alongside large, forward-reaching Transverse processes. These structures reinforce the lower back against rotational twisting.

D. Sacrum (Pelvic Region — 4 Fused Vertebrae)

To provide a rigid anchor for the hind limbs during locomotion, the pelvic vertebrae fuse into a single solid structural unit.

- **Structure:** Composed of 4 distinct vertebrae completely fused together to form a single, heavy, wedge-shaped bone called the Sacrum.
- **Identification Feature:** The broad, wing-like anterior lateral margins form a tight, immovable joint (Sacroiliac joint) with the ilium of the pelvic girdle. It is pierced by pairs of sacral foramina for spinal nerves.

E. Caudal Vertebrae (Tail Region — 15 in Rabbit, 27-30 in Rat)

- **Structure:** Display a pattern of progressive structural reduction toward the posterior end.
- **Identification Feature:** The initial caudal vertebrae possess complete arches. As you move down the tail, the neural spines, zygapophyses, and neural arches completely disappear, leaving the final tail segments as simple, solid, cylindrical rods of bone consisting solely of the centrum.

Practical Laboratory Spotting Key

When identifying loose mammalian bones from a skeleton tray during practical exams, look for these definitive landmarks:

1. **The Naked Ring:** If the bone looks like a flat steering wheel or ring, has wide side wings, and completely lacks a central body cylinder (*centrum*), it is the **Atlas vertebra**.
2. **The Pegged Pivot:** If the bone features a prominent vertical tooth/peg (*odontoid process*) projecting from its main block, it is the **Axis vertebra**.
3. **The Twin Pinhole Windows:** If the bone is relatively small, flat-faced, and has a tiny pinhole canal (*vertebrarterial canal*) drilled into the base of each side arm, it is a **Typical Cervical vertebra**.
4. **The Backward Spear:** If the bone has a thin, long neural spine that points sharply backward like a spear, along with smooth dimples (*costal facets*) on its sides, it is a **Thoracic vertebra**.
5. **The Forward Winged Heavyweight:** If the bone is remarkably heavy and thick, with side processes that point forward like aircraft wings, it is a **Lumbar vertebra**.
6. **The Shield Matrix:** If the specimen consists of multiple segments fused into a wide, porous shield with rough, sand-paper-like sides for hip attachment, it is the **Sacrum**.

APPENDICULAR SKELETON OF A RAT

1. Pectoral Girdle & Forelimb Bones

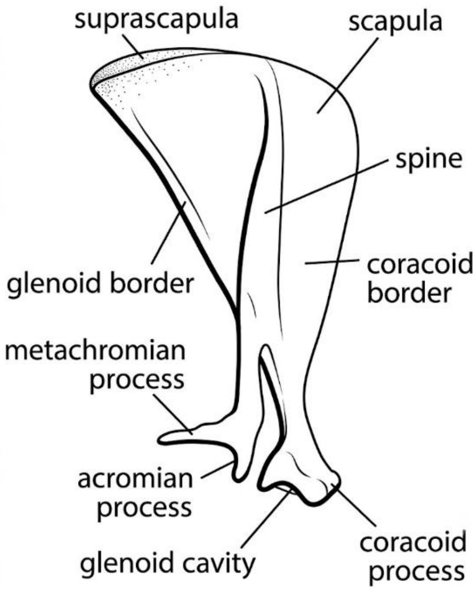
The pectoral (shoulder) complex is loosely attached to the axial skeleton via muscles (**synsarcosis**), providing maximum shock absorption during running and landing.

Forelimb Bone Flowchart

Pectoral Girdle (Scapula-Coracoid) ──► Humerus ──► Radius & Ulna ──►
Carpals ──► Metacarpals ──► Phalanges

A. Pectoral Girdle (Scapula)

- **Anatomical Structure:** In mammals, the pectoral girdle is reduced to a single prominent, flat, triangular bone called the Scapula (shoulder blade). The coracoid is reduced to a tiny, curved knob-like coracoid process fused to the scapula's neck.



Pectoral Girdle of Rabbit

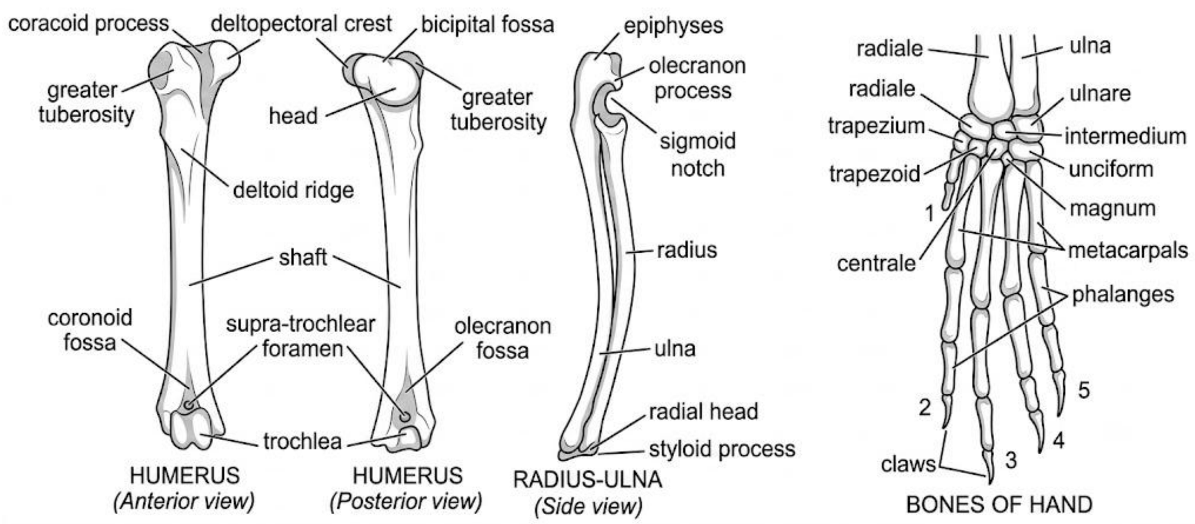
- **Identification Features**
  - **Scapular Spine:** A prominent, sharp bony ridge runs along the outer flat surface of the triangle.
  - **Acromion & Metacromion Processes:** The spine terminates at its lower end in an expanded **acromion process**. In rabbits, a sharp, backwardly directed branch called the **metacromion** is highly prominent (less pronounced in rats).
  - **Glenoid Cavity:** A smooth, shallow socket at the narrow apex of the triangle that articulates with the head of the humerus.
  - **Clavicle:** A slender, rod-like bone that links the acromion to the sternum, keeping the shoulders braced.

B. Humerus (Upper Arm Bone)

- **Anatomical Structure:** A strong, elongated, straight bone forming the upper forelimb segment.
- **Identification Features:**
  - **Proximal End:** Bears a smooth, rounded head that fits into the glenoid cavity, flanked by two rough bumps called the greater and lesser tuberosities.
  - **Deltoid Ridge:** A prominent V-shaped muscular crest runs down the anterior surface of the upper shaft.
  - **Distal End:** Features a pulley-like articulating surface called the trochlea.
  - **Supratrochlear Foramen:** A diagnostic pinhole aperture located just above the trochlea through which the olecranon process passes during extension (highly distinct in both rats and rabbits).

C. Radius & Ulna (Forearm Bones)

- **Anatomical Structure:** The mammalian forearm consists of two separate, parallel bones. The Ulna is longer and stouter than the Radius.
- **Identification Features:**
  - **Olecranon Process:** The proximal end of the ulna projects upward beyond the joint as a prominent, rough lever extension. This forms the point of the elbow for muscle attachments.
  - **Sigmoid Notch (Greater Sciatic Notch):** A deep, half-moon-shaped curve just below the olecranon process that articulates with the trochlea of the humerus.
  - **Spatial Alignment:** The radius is smaller and crosses slightly over the front of the ulna. In rats and rabbits, these bones are bound tightly by interosseous tissue, limiting rotation (*pronation/supination*) to ensure stability during running.



2. Pelvic Girdle & Hind Limb Bones

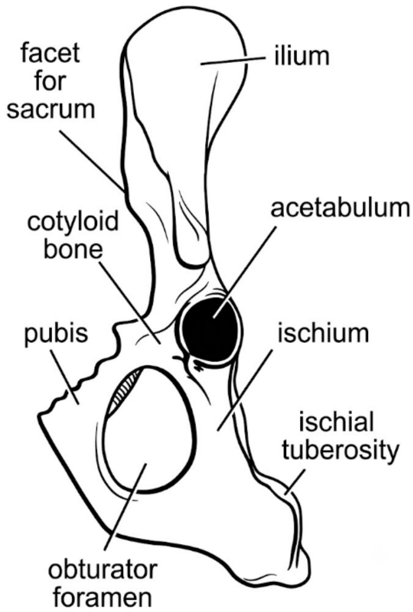
The pelvic (hip) complex is rigidly fused to the sacral vertebrae to transmit the driving force generated by the powerful hind limbs directly to the spine.

Hind limb Bone Flowchart

Pelvic Girdle (Innominate) ──► Femur ──► Tibia & Fibula ──► Tarsals ──► Metatarsals ──► Phalanges

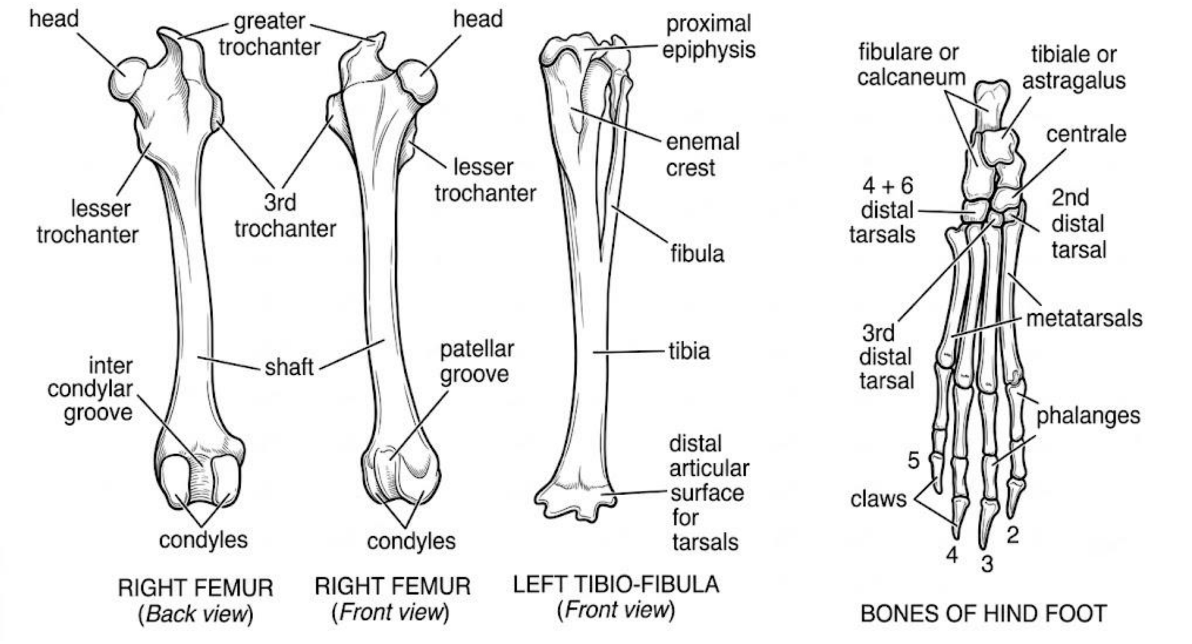
A. Pelvic Girdle (Os Innominatum)

- **Anatomical Structure:** Composed of two identical symmetrical halves called innominate bones. Each half is formed by the fusion of three primary embryonic bones: Ilium, Ischium, and Pubis.



Pelvic Girdle of Rabbit (lateral view)

- **Identification Features**
  - **Acetabulum:** A deep, cup-shaped, circular socket located at the junction of the three bones. It receives the head of the femur.
  - **Ilium:** The long, forward-reaching blade that features a rough interior facet for secure attachment to the sacrum.
  - **Ischium:** The heavy posterior loop forming the back wall of the hip. It terminates in a thickened **ischial tuberosity** (the sitting bone).
  - **Pubis:** The thin ventral bone that meets its counterpart from the opposite side along the midline at the **pubic symphysis**.
  - **Obturator Foramen:** A massive, smooth window-like opening bounded by the ischium and pubis, serving as a passage for nerves and blood vessels.



Hind limb bone of the rabbit

B. Femur (Thigh Bone)

- **Anatomical Structure:** The longest, heaviest, and strongest cylindrical bone in the appendicular skeleton, adapted to bear the animal's weight.
- **Identification Features:**
  - **Proximal End:** Bears a distinct, smooth, spherical **head** mounted on a noticeable, constricted **neck**. This head projects inward at an angle to fit securely into the deep acetabulum.
  - **Trochanters:** Bony projections for heavy muscle insertions:
    1. **Greater Trochanter:** A massive ridge aligned with the outer shaft.
    2. **Lesser Trochanter:** A small knob situated below the neck base.
    3. **Third Trochanter:** A small, sharp shelf projecting from the outer margin of the shaft below the greater trochanter (highly diagnostic of rodents like rats and lagomorphs like rabbits).
  - **Distal End:** Broadens into two smooth, rounded, backward-facing rollers called the medial and lateral condyles, separated by an intercondylar fossa.

C. Patella (Knee Cap)

- **Identification Feature:** A small, heart-shaped sesamoid bone that develops inside the primary extensor tendon. It glides within the smooth groove on the front of the femur's distal joint to protect the knee.

D. Tibia & Fibula (Shank Bones)

- **Anatomical Structure:** The lower hind limb bones demonstrate adaptation for leaping and cursorial locomotion through partial fusion.

- **Identification Features:**
  - **Tibia:** The primary shin bone. It is exceptionally large, robust, and features a sharp, curved cnemial crest running down its upper anterior surface.
  - **Fibula:** A slender, needle-like bone.
  - **The Fusion Point:** While the proximal ends are separate, the lower halves of the tibia and fibula are completely fused into a single composite bone structure in both rats and rabbits. This structural fusion prevents twisting and reinforces the leg during high-impact landings.

Practical Laboratory Spotting Key

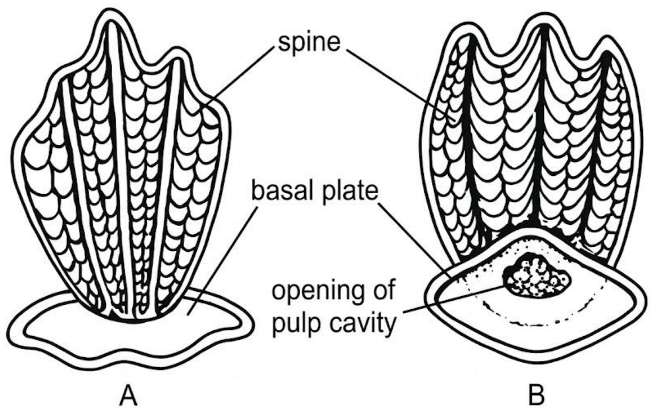
When identifying loose appendicular bones from a laboratory specimen tray during practical examinations, use these diagnostic criteria:

1. **The Triangle with a Spine:** If the specimen is a flat, thin, triangular plate featuring a sharp ridge running down its center that terminates in a hook (*acromion*), it is the **Scapula**.
2. **The Pierced Pulley:** If the bone is a straight rod with a smooth, round head at the top and a distinct pinhole window (*supratrochlear foramen*) drilled through the bottom pulley joint, it is the **Humerus**.
3. **The Elbow Scoop:** If the bone features a deep, smooth, half-moon crescent notch (*sigmoid notch*) flanked by a rough, protruding rear lever block (*olecranon*), it is the **Ulna**.
4. **The Three-Headed Hip Shield:** If the specimen looks like a wide, asymmetrical frame with a large, open oval window (*obturator foramen*) and a deep, circular cup socket (*acetabulum*) on its side, it is an **Innominate bone (Pelvic Girdle)**.
5. **The Off-Center Sphere with a Side Shelf:** If the bone is exceptionally long and heavy, featuring an isolated sphere head mounted on a distinct neck, alongside a noticeable side shelf projection (*third trochanter*) halfway down the shaft, it is the **Femur**.
6. **The Double-Fused Arrow:** If the bone is highly robust, has a sharp ridge at its top, and splits at the upper end into a thick bar and a thin needle but fuses completely into a single bone at the bottom, it is the **Tibia-Fibula**.

MOUNTING OF FISH SCALES (PLACOID, CYCLOID AND CTENOID)

Fish scales are dermal derivatives that form the protective exoskeleton of fish. These are mineralized structures originating from the dermis, the skin's deeper layer. Arranged in an overlapping pattern, they form a flexible, protective exoskeleton. This dermal armor provides a mechanical shield against predators and physical trauma, reduces hydrodynamic drag during swimming, and acts as a vital barrier against pathogens and osmoregulatory stress.

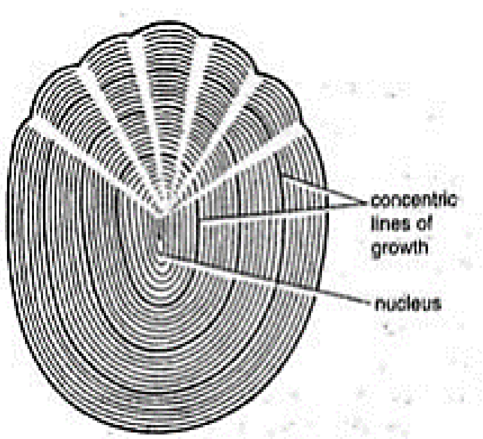
A. Placoid Scales



Placoid Scale: A: Dorsal view   B: Ventral view

- **Diagnostic Features:** Characteristic trident (three-pronged) spine that projects backward, arising from a diamond-shaped or quadrate basal plate.
- **Composition:** The spine is made of dentine covered by an enamel-like substance (*vitrodentine*), housing an internal pulp cavity.
- **Occurrence:** Found exclusively in cartilaginous fishes (Chondrichthyes like sharks, e.g., *Scoliodon*).

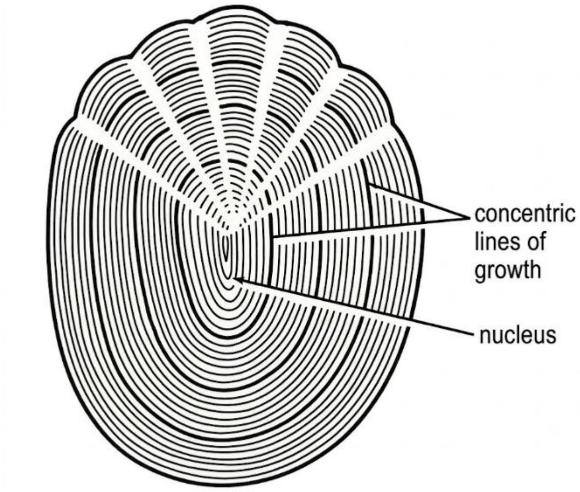
B. Cycloid Scales



Cycloid Scale

- **Diagnostic Features:** Smooth, circular or oval, thin, translucent plates. They exhibit a central point, the focus, surrounded by concentric growth rings, called circuli (lines of growth), and radiating lines, called radii.
- **Composition:** Acellular bone and collagen fibers; they lack enamel and dentine.
- **Occurrence:** Found in lungfishes and soft-rayed bony fishes (Osteichthyes like *Labeo rohita* / Rohu, Catla).

C. Ctenoid Scales



Ctenoid Scales

- **Diagnostic Features:** Similar to cycloid scales in shape and composition but distinguished by a comb-like row of small spines or teeth called **ctenii** along their posterior margin.
- **Composition:** Acellular bone. The comb-like teeth reduce hydrodynamic drag during swimming.
- **Occurrence:** Found in modern spiny-rayed bony fishes (Osteichthyes like *Anabas* / Climbing Perch, Perches).

2. Requirements for the Practical

- **Biological Material:** Preserved or fresh skin pieces of Shark (*Scoliodon*) for Placoid scales; skin/body scales of Rohu (*Labeo*) for Cycloid scales; skin/body scales of *Anabas* or any perch for Ctenoid scales.
- **Reagents:** 5–10% Potassium Hydroxide (KOH) or Sodium Hydroxide (NaOH) solution, 10% Glacial Acetic Acid or dilute Hcl (optional, for decalcification/cleaning), Borax Carmine or Eosin stain, Ethanol grades (30%, 50%, 70%, 90%, Absolute), Xylene, and Glycerin or DPX mountant.
- **Apparatus:** Test tubes, watch glasses, spirit lamp/burner, forceps, fine needles, camel hair brush, microscopic slides, coverslips, and a compound microscope.

3. Step-by-Step Laboratory Procedure

Because placoid scales are firmly embedded deep in mammalian-like tough dermis, they require a chemical isolation step that cycloid and ctenoid scales do not.

Protocol I: Isolation and Preparation

For Placoid Scales (Shark Skin)

1. **Tissue Digestion:** Cut a small piece (approx. 1 cm) of preserved shark skin. Place it in a test tube containing 5–10% KOH or NaOH solution.
2. **Boiling:** Gently heat the test tube over a spirit lamp for 2 to 3 minutes. The strong alkali will dissolve the soft epidermal and dermal tissues, releasing the hard, alkali-resistant placoid scales.

Caution: Do not over boil, or you risk damaging the basal plates.

1. **Sedimentation & Washing:** Allow the scales to settle to the bottom of the tube. Carefully decant the alkaline solution. Fill the tube with water, shake gently, and let the scales settle again. Repeat this wash 3 to 4 times to completely eliminate any remaining alkali.

For Cycloid and Ctenoid Scales (Bony Fish Skin)

1. **Extraction:** Using fine forceps or a scalpel, gently scrape a few scales from the lateral or dorsal region of a bony fish, moving in the direction of the tail.
2. **Cleaning:** Place the pulled scales in a watch glass containing water. Use a fine camel hair brush to gently scrub away any clinging mucus, tissue debris, or silver epidermal pigmentation. If the mucus is stubborn, soak the scales in a 1% KOH solution for 1 minute, then wash thoroughly with water.

Protocol II: Staining, Dehydration, and Mounting (Shared Steps)

Once you have isolated clean scales in a watch glass, proceed with the temporary or permanent mounting sequence

Mounting Protocol Flowchart

Clean Scales ──► Stain (Borax Carmine/Eosin) ──► Dehydration (Ethanol Grades) ──► Clearing (Xylene) ──► Mounting (DPX / Glycerin)

1. **Staining:** Transfer the cleaned scales into a watch glass containing Borax Carmine or Eosin stain for 2 to 3 minutes.
2. **Destaining (If overstained):** Wash briefly with acid-alcohol (70% alcohol containing a drop of Hcl to remove excess or muddy stain, ensuring the structural rings or spines stand out sharply.
3. **Dehydration:** Pass the stained scales through a graded series of ascending alcohol concentrations to extract water:

- 30% Ethanol (1 minute)

- 50% Ethanol (1 minute)
- 70% Ethanol (1 minute)
- 90% Ethanol (1 minute)
- Absolute Alcohol / 100% Ethanol (2 minutes, to completely dehydrate).

1. **Clearing:** Transfer the completely dehydrated scales into a watch glass containing **Xylene** for 1 to 2 minutes. The scales will immediately turn translucent and clear.
2. **Mounting**

- **For Permanent Mounts:** Place a clean, dry glass slide on your workspace. Use a camel hair brush or forceps to transfer a cleared scale to the center of the slide. Add a single drop of DPX mountant over the scale. Gently lower a clean coverslip at a 45° angle using a needle to prevent air bubbles.
- **For Temporary Mounts:** Skip the alcohol and xylene stages. Transfer washed, stained scales directly to a slide, add a drop of Glycerin, and apply a coverslip.

4. Practical Laboratory Observations & Spotting Key

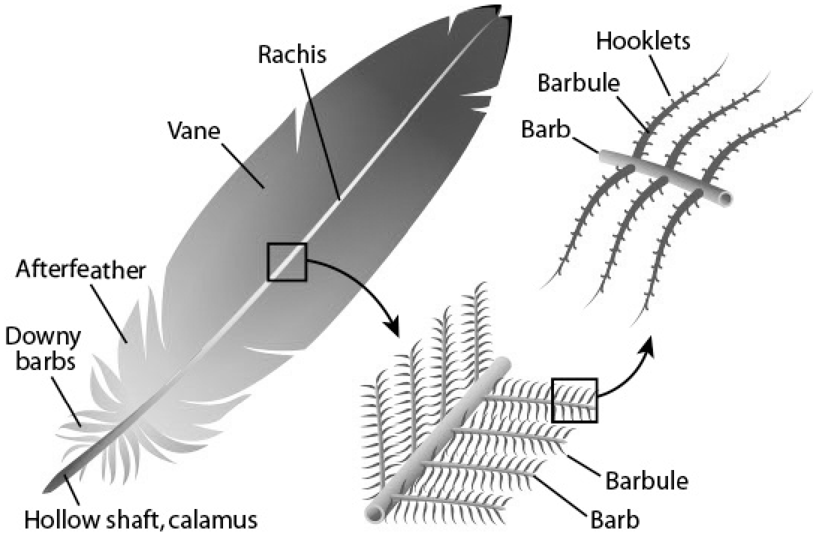
When you place your mounted slide under the low power (10 times) objective of a compound microscope, check for these explicit configurations to confirm a successful mount:

- **Placoid Scale Spotter:** You should see distinct, sharp, dark pink or red trident spikes pointing uniformly in one direction, anchored to an underlying diamond-shaped plate. Individual scales look like mini anchors.
- **Cycloid Scale Spotter:** You should see a wide, clear plate without any spines. Look for the central **focus** point and trace the fine, concentric ring lines (**circuli**) radiating outwards like the rings inside a tree trunk.
- **Ctenoid Scale Spotter:** Look at the margins of the scale. One semi-circular edge will appear smooth with concentric circuli lines, while the opposite straight edge will display a dense, comb-like arrangement of sharp teeth (ctenii).

STUDY OF FEATHERS IN AVES

General Structure of a Typical Flight Feather (Contour Feather)

To understand feather modifications, students must first master the structural landmarks of a standard contour feather (e.g., from a pigeon). It consists of two primary regions: The **Axis (Stem)** and the **Vane (Vexillum)**.



A. The Axis (Stem)

Divided into two distinct parts:

1. **Quill (Calamus):** The lower, hollow, semi-transparent cylindrical base that is embedded directly into the feather follicle of the skin.

- **Inferior Umbilicus:** A tiny pit at the extreme base of the quill that receives a vascular dermal papilla supplying nutrients during the feather's growth phase.
- **Superior Umbilicus:** A small aperture at the junction where the hollow quill meets the solid, vane-bearing shaft. A small, rudimentary accessory feather called the after shaft (hypo rachis) often arises near this point.

2. **Shaft (Rachis):** The solid, opaque, longitudinal upper portion of the axis that supports the wide part of the feather. It is grooved along its ventral surface.

B. The Vane (Vexillum)

The flat, broad, continuous sheet of the feather extending laterally from either side of the rachis. Its structural integrity is maintained by an interlocking microscopic mesh system:

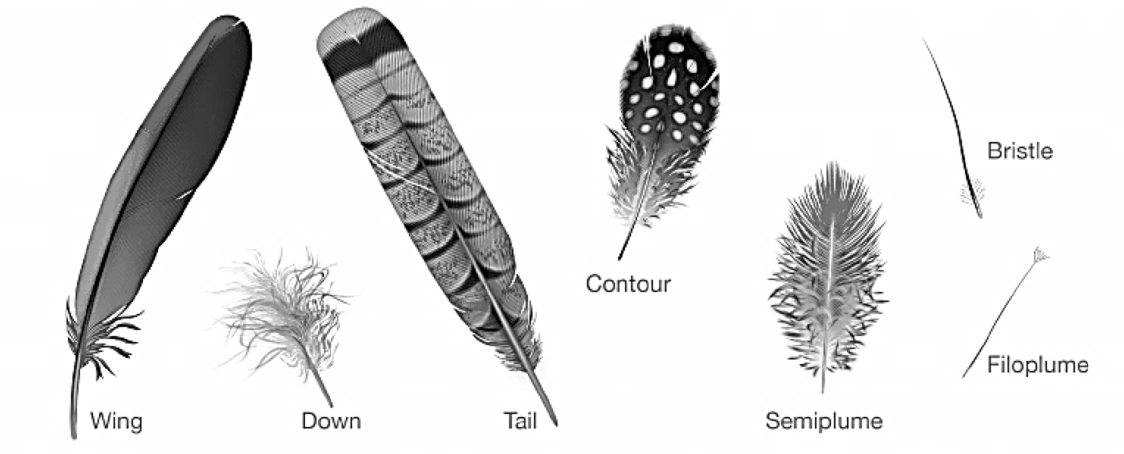
- **Barbs:** Linear, thin, blade-like branches extending obliquely outward from both lateral margins of the rachis.
- **Barbules:** Microscopic lateral branches extending from both sides of each barb. They are differentiated based on direction:

- **Anterior Barbules:** Point toward the tip of the feather and bear tiny, hook-like structures called **hamuli (hooklets)**.
- **Posterior Barbules:** Point toward the base of the feather and feature simple, smooth, rolled or grooved upper margins (*flanges*).

- **Interlocking Mechanism:** The hooks (*hamuli*) of the anterior barbules catch securely onto the grooved flanges of the posterior barbules of the adjacent barb. This forms a flexible, airtight, and wind-resistant surface essential for flight.

Types of Feathers

Avian plumage is modified into five major distinct categories based on size, location, and functional requirements



Types of Feathers

1. Contour Feathers

- **Structure:** Possesses a well-developed calamus, a rigid rachis, and a broad, perfectly interlocking vane system.
- **Functional Adaptation:** Covers the exterior framework of the bird's body, giving it a streamlined, aerodynamic shape.
- **Sub-types (Flight Feathers)**
  - **Remiges:** Large, asymmetrical contour feathers found on the wings, responsible for generating lift and propulsion during flight.
  - **Rectrices:** Large, symmetrical contour feathers arranged in a fan-like pattern on the tail, acting as a rudder for steering and braking.

2. Down Feathers (Plumules)

- **Structure:** The quill is short and weak. The rachis is either completely absent or drastically reduced. Consequently, long, soft barbs arise in a fluffy cluster directly from the tip of the quill. Barbules lack hamuli/hooks, meaning the barbs cannot interlock.

- **Functional Adaptation:** Traps a layer of stagnant air close to the skin, providing excellent thermal insulation to conserve body heat. They form the exclusive covering of nestling chicks.

3. Filoplumes (Hair Feathers)

- **Structure:** Microscopic, delicate, hair-like feathers. They feature an elongated, slender, thread-like rachis with a tiny, tuft-like cluster of a few un-interlocked barbs at the very tip.
- **Functional Adaptation:** Scattered thinly among the contour feathers. They contain sensory nerve endings at their base and function as proprioceptors, alerting the bird to aerodynamic displacements of the outer feathers.

4. Bristles

- **Structure:** Feature a stiff, rigid, heavily keratinized rachis that is completely naked. A few rudimentary, un-interlocked barbs may occur only at the extreme base of the quill.
- **Functional Adaptation:** Located around the mouth, nostrils, and eyes. They act as protective filters (eyelashes) or help catch insects' mid-air (acting as a wider funnel around the mouth in insectivorous birds like nightjars and flycatchers).

5. Powder-Down Feathers

- **Structure:** Similar to regular down feathers, but their barbs continuously disintegrate at their tips into a fine, water-resistant talcum-like powder made of keratin.
- **Functional Adaptation:** Found in specific patches (e.g., herons, pigeons). The bird uses this powder during preening to waterproof and clean its feathers.

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