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HANDOUT OF ZOOLOGY

MAMMALS

"GENERAL CHARACTERISTICS AND CLASSIFICATION"

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Preface

Understanding the biology and classification of mammals is an important step in the training of veterinary students. The study of mammals is one of the most important chapters in the zoology program. Mammals are a large and complex group, with unique physical, anatomical, and behavioral traits.

The current course handout is the result of my personal insights based on my teaching experience in zoology. According to the national veterinary program, it is intended for first-year students of veterinary medicine.

This course handout is structured in two chapters:

Chapter one focuses on the general characteristics of mammals. In this chapter, we have compiled general concepts regarding the morphology, anatomy, and physiology of mammals. Supported by illustrations, we will successively study: the skeleton, muscles, fur, nervous system, digestive system, respiratory system, circulatory system, lymphatic system, excretory system, and reproductive system.

Chapter two is dedicated to the classification of mammals. We will explore all currently existing mammals through a simplified and updated description of the different orders of mammals, accompanied by photos.

Finally, we have concluded the document with a list of bibliographical references that include the sources used for the information presented.

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CHAPTER I:

GENERAL CHARACTERISTICS OF MAMMALS

Introduction:

Mammals are a diverse group of vertebrates belonging to the class Mammalia, characterized by their ability to nurse their young with milk produced by mammary glands. They exhibit a wide range of adaptations, enabling them to thrive in various habitats, from terrestrial to aquatic environments. Mammals are distinguished by features such as a warm-blooded nature, a body covered with hair or fur, and a highly developed nervous system that supports complex behaviors and learning. Their heterodont dentition, advanced respiratory and circulatory systems, and parental care contribute to their evolutionary success. From the tiniest shrews to the largest whales, mammals play a crucial role in ecosystems worldwide[1].

In this first chapter, we will successively study: the skeleton, muscles, fur, nervous system, digestive system, respiratory system, circulatory system, lymphatic system, excretory system, and reproductive system.

1. Skeleton

The skeleton, composed of bones, joints, and their supporting structures, plays a crucial role in providing support and protection to the body while enabling movement through the coordination of the nervous system and muscles.

1.1. Mammalian skeletal structure:

The mammalian skeleton is divided into two main regions: the axial skeleton and the appendicular skeleton. The axial skeleton includes the vertebral column, ribs, and sternum, providing the body's primary support and facilitating movement through flexion and extension. It comprises five regions: cervical, thoracic, lumbar, sacral, and caudal. The appendicular skeleton consists of the pelvic and pectoral girdles and their associated limbs, enabling locomotion. Most mammals are tetrapods and therefore have four limbs. However, marine mammals, such as cetaceans (whales) and sirenians (manatees and sea cows), have evolved significant adaptations; their hind limbs are vestigial and not externally visible[1].

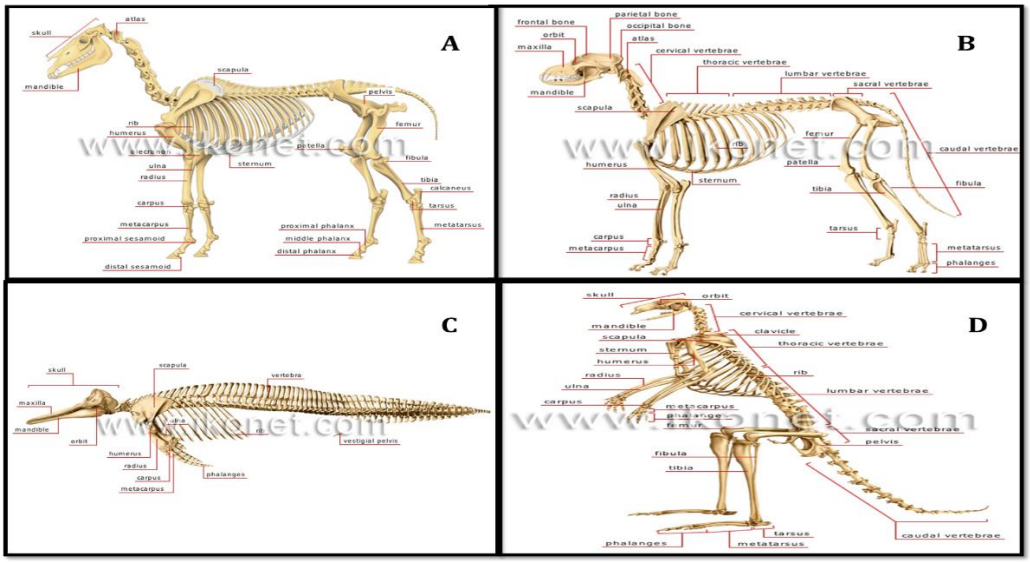


Figure 1. Comparative mammalian skeletal anatomy: (A) Horse, (B) Dog, (C) Dolphin, and (D) Kangaroo.
(https://www.ikonet.com/en/visualdictionary/animal-kingdom)

1.2. Locomotor adaptations in terrestrial mammals:

Terrestrial mammals exhibit various locomotor adaptations: plantigrade species, such as apes, bears, and raccoons, walk on the soles of their feet; digitigrade animals, like cats and dogs, walk on their toes; and unguligrade mammals, such as horses, walk on the tips of their toes (hooves). These adaptations reflect the diverse lifestyles and environments that mammals inhabit [2,3].

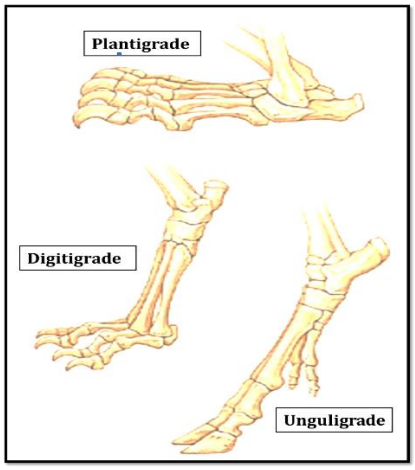


Figure 2. Different structures of mammalian limbs.
(https://www.larousse.fr/encyclopedie/images/Locomotion_des_mammif%C3%A8res/1003400)

2. Muscles

2.1. Type of muscles in mammals:

Mammalian muscles are categorized into three distinct types: skeletal, cardiac, and smooth, each with unique structural and functional characteristics. Skeletal muscles are voluntary muscles attached to bones, facilitating movement and posture. They are composed of long, cylindrical fibers with multiple nuclei and exhibit a striated appearance due to the organized arrangement of actin and myosin filaments[4].

Cardiac muscle, found exclusively in the heart, is an involuntary, striated muscle responsible for pumping blood throughout the body. Cardiac muscle cells, or cardiomyocytes, are branched and interconnected by intercalated discs, which facilitate synchronized contractions essential for maintaining a consistent heartbeat[4].

Smooth muscle is non-striated and involuntary, located within the walls of hollow organs such as blood vessels, the gastrointestinal tract, and the respiratory system. These spindle-shaped cells are responsible for various functions, including regulating blood flow, peristalsis in the digestive tract, and controlling airflow in the respiratory pathways[4].

The diversity in structure and function among these muscle types enables mammals to perform a wide range of movements and maintain essential physiological processes.

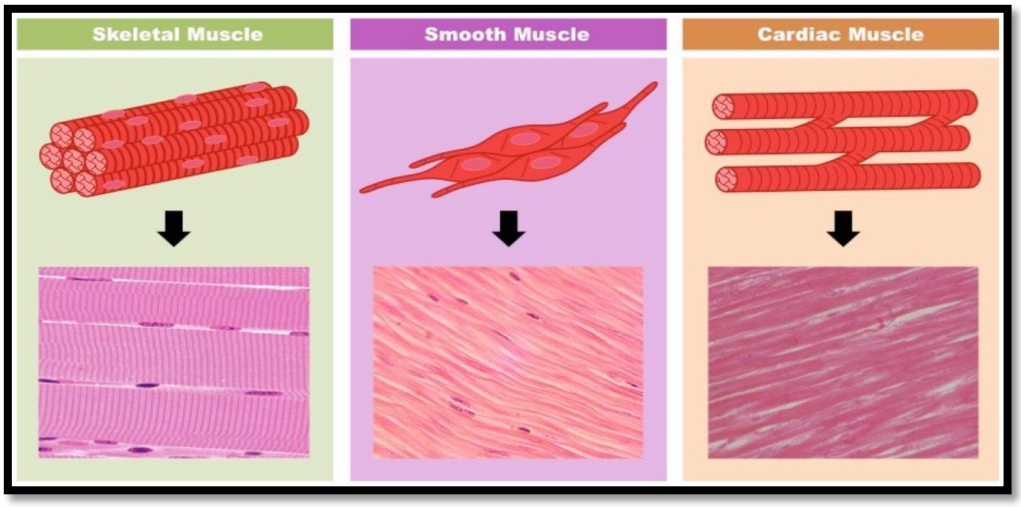


Figure 3. Different types of muscles in mammals.
(https://old-ib.bioninja.com.au/higher-level/topic-11-animal-physiology/112-movement/types-of-muscles.html)

2.2. Role and differences between muscle types across species:

The skeleton, serving as a true bony framework, is mobilized by muscles (commonly referred to as meat or flesh) that attach to bones in ways that optimize movement and, often, the force required. These muscles are harmoniously aligned with the skeletal structure and the animal's lifestyle. A muscle absent in one species may be highly developed in another; for instance, whales lack distinct neck muscles, whereas primates possess well-developed ones. Mammals that climb, burrow, or fly have robust pectoral muscles to facilitate arm flexion; those adapted for running exhibit strong thigh and hip muscles; species utilizing their tails as a fifth limb have highly developed muscles in that region; and facial muscles are absent in the platypus but are highly developed in carnivores. In essence, each animal's musculature is organized according to its mode of life[5].

Similarly, aquatic mammals like cetaceans display muscle fiber adaptations that support their swimming lifestyle. Studies have shown that their locomotor muscles are mainly composed of large type I fibers, which are suited for sustained contractions during long-duration dives[6].

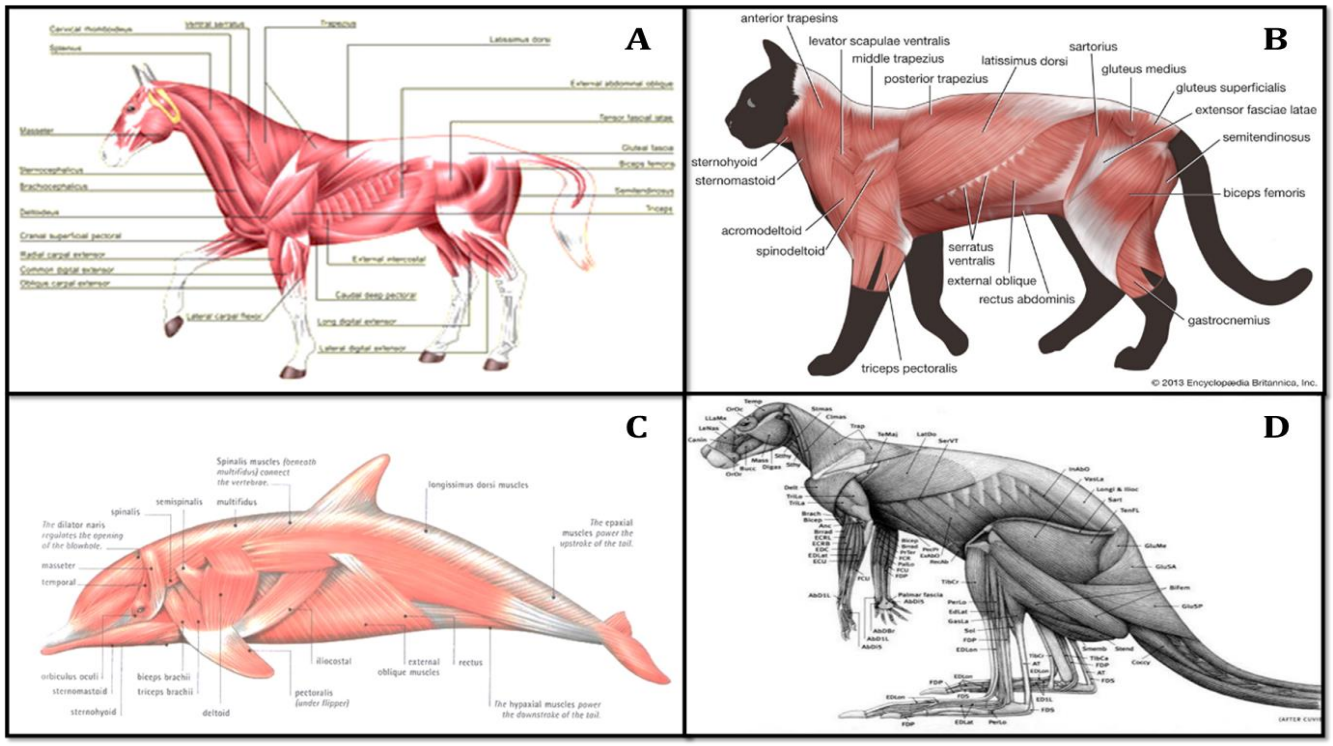


Figure 4. Comparative anatomy of mammalian muscles: (A) Horse, (B) Cat, (C) Dolphin, and (D) Kangaroo.

(https://stock.adobe.com/dz/)

3. Hair or fur:

Hair, commonly referred to as fur or pelage in mammals, is a distinctive feature that sets this class of animals apart. Composed primarily of keratinized epidermal cells formed in hair follicles located in the dermal layer of the skin, hair serves multiple essential functions, including thermoregulation, protection, sensory perception, waterproofing, and camouflage[7].

3.1. Structure of mammalian hair

The hair shaft is primarily composed of keratin and consists of three distinct layers: the cuticle, the outermost layer made up of dead, transparent cells arranged in overlapping patterns; the cortex, located beneath the cuticle, often thick and may contain pigment; and the medulla, the central core present in most hairs, composed of large, cuboidal cells interspersed with air pockets, often exhibiting distinctive coloration. The specific characteristics of these layers including the arrangement of cuticular scales, as well as the thickness, pigmentation of the cortex, and the distribution and color of medulla cells are frequently species-specific[8].

3.2. Color of mammalian hair

Hair pigmentation is primarily determined by two types of melanin: eumelanin and pheomelanin. Eumelanin is very dark, while pheomelanin is paler and contributes to lighter shades. Many individual hairs exhibit alternating bands of these pigments, a pattern known as agouti. White hair lacks pigment entirely, whereas black hair results from a predominance of eumelanin. The overall coloration of an animal's pelage is influenced by the specific colors of these bands, their relative sizes, and the distribution of hairs with varying banding patterns[8].

3.3. Type of mammalian hair

The pelage of most mammals consists of more than one kind of hair. The most noticeable hairs are the guard hairs, which cover the fur and protect it. Guard hairs can sometimes change into defensive spines (like in porcupines, where the scales on the hair form sharp barbs), bristles (long, stiff hairs that grow continuously, like the mane of a lion), or awns (hairs that don’t grow all the time and have a wider tip and a thinner base). Underneath the guard hairs, there is usually a layer called underfur, which can be made of wool (hairs that keep growing), fur (short hairs that stop growing after a certain length), and/or velli (soft, fuzzy hairs)[8].

An important type of hair is the vibrissae, or whiskers. These hairs are long, straight, and stiff, and their bases have many nerves. Vibrissae are very sensitive to touch and help the animal

sense its surroundings. These whiskers are usually found in specific places on the body and can form small groups. We all know the whiskers on a dog's face, but they can also appear on other parts of the body, like on a squirrel's ankles or on the back of some bats that live in tight spaces[9].

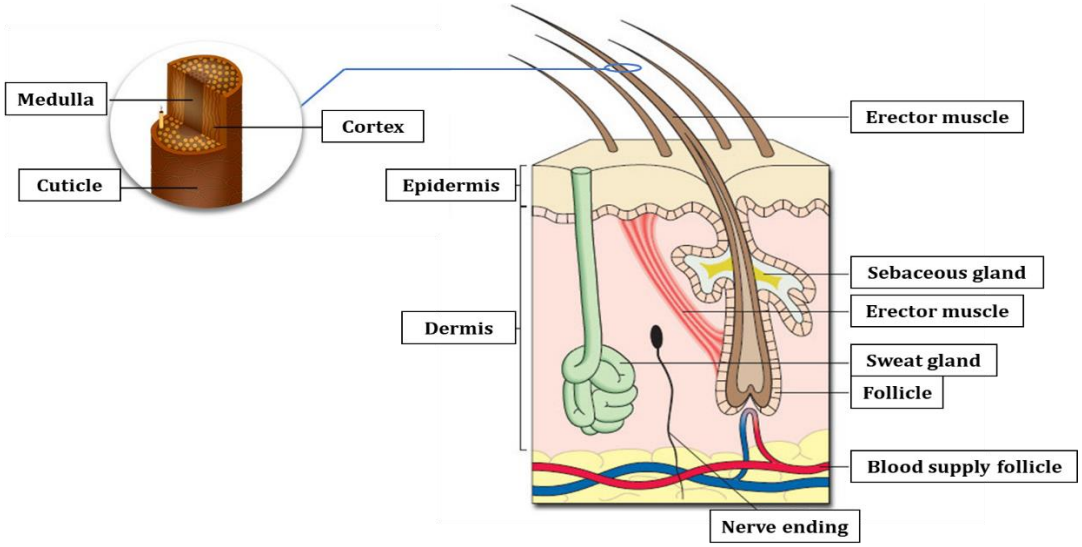


Figure 5. Structure of mammalian hair.
(https://www.open.edu/openlearn/nature-environment/introducing-mammals/content-section-7)

4. Nervous system

The nervous system is a highly specialized and intricate network that governs mammalian activities, allowing them to interact effectively with their environment and maintain internal homeostasis. It serves as the body's primary communication and control center, integrating sensory input, processing information and initiating appropriate responses. The nervous system is essential for the regulation of a wide range of functions, from basic physiological processes to complex behaviors[10].

4.1. Structure of mammalian nervous system

In mammals, the nervous system is organized into two main components:

The central nervous system (CNS): Consisting of the brain and spinal cord, the CNS acts as a command center, processing information and coordinating activities throughout the body[10,11].

Peripheral Nervous System (PNS): Consisting of nerves and ganglia outside the CNS, the PNS connects the central system to the rest of the body and transmits sensory and motor signals[10,11].

It is also functionally divided into the somatic nervous system, which controls voluntary movement and sensation, and the autonomic nervous system, which controls involuntary functions such as heart rate, digestion and respiration[10,11].

Mammals have a highly developed nervous system, characterized by a large and complex brain, particularly the cerebral cortex, which supports advanced cognitive functions such as learning, memory and problem solving. This intricate system not only enables survival, but also underpins the adaptive behaviors that define mammalian ecological success[10,11].

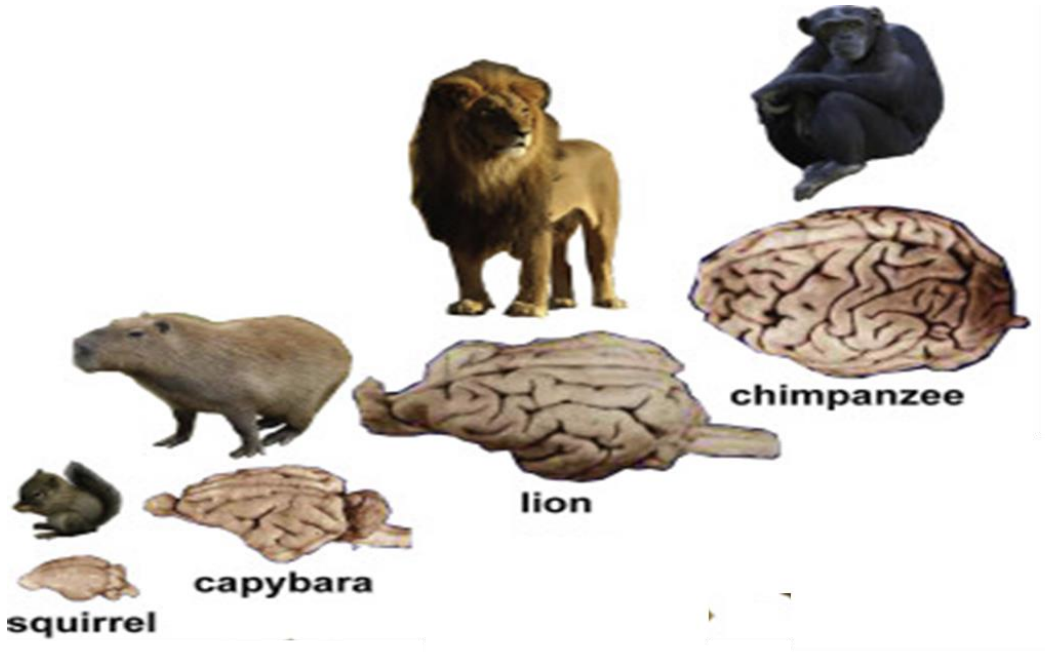


Figure 6. Species variation in mammalian brains.
(https://www.sciencedirect.com/science/article/abs/pii/S0065215615000034)

4.2. Mammalian sense organs

Mammals possess a sophisticated array of sense organs that enable them to perceive and interpret their environment, facilitating survival and interaction. These organs are specialized to detect specific stimuli and convert them into neural signals processed by the nervous system. The primary sense organs in mammals include[12,13]:

4.2.1. Eyes (Vision): The eyes are complex organs that detect light and enable vision. Photoreceptor cells within the retina, known as rods and cones, respond to light intensity and color, respectively, allowing mammals to perceive images and motion[12,13].

4.2.2. Ears (Hearing and Balance): The ears serve dual functions: auditory perception and balance. The outer, middle, and inner ear structures work together to transmit sound waves to the cochlea, where mechanoreceptors convert them into neural signals for hearing. Additionally, the vestibular system within the inner ear detects changes in head position and movement, maintaining equilibrium[12,13].

4.2.3. Nose (Olfaction): The olfactory system is responsible for the sense of smell. Olfactory receptors in the nasal cavity bind to airborne chemical molecules, initiating neural responses that result in odor perception. This sense is crucial for detecting food, predators, and pheromones[12,13].

4.2.4. Tongue (Gustation): Taste buds on the tongue contain chemoreceptors that detect soluble chemicals, leading to the perception of taste[12,13].

4.2.5. Skin (Somato-sensation): The skin is the largest sensory organ, equipped with various receptors that detect touch, pressure, temperature, and pain. These receptors enable mammals to perceive tactile information, respond to environmental changes, and protect against harmful stimuli[12,13].

5. Digestive system

Mammals exhibit a remarkable diversity in their digestive systems, each finely tuned to their specific dietary habits. These adaptations are broadly categorized based on dietary preferences

5.1. Digestive tract

The digestive tract varies among species based on dietary needs, with distinct anatomical and physiological adaptations observed in carnivores, herbivores, and omnivores.

5.1.1. Mouth and teeth

The mouth is the most cranial part of the digestive system, responsible for the mechanical and enzymatic breakdown of feed. It contains structures like the teeth and tongue, which play crucial roles in reducing food particle size. Teeth are classified by their location and function:

- ✓ **Incisors:** Located at the front, used for cutting food.
- ✓ **Canines:** Used for tearing, positioned behind the incisors.
- ✓ **Premolars and Molars:** Located posteriorly, used for grinding food.

Salivary glands in the oral cavity release enzymes that begin the chemical digestion of carbohydrates, while the tongue aids in maneuvering and mixing feed. Specialized structures like papillae on the tongue provide traction and assist in taste differentiation, which is facilitated by taste buds[14].

5.1.2. Esophagus

The esophagus is a muscular tube connecting the pharynx to the stomach. It passes through the thoracic cavity within the mediastinal space, then traverses the diaphragm to reach the stomach. Feed and liquids are transported by peristaltic muscular contractions, ensuring one-way movement. The esophagus is normally closed at both ends by sphincters, the cranio-esophageal sphincter at the upper end and the physiological closure at the stomach's opening (cardia). This prevents backflow and protects the airway during swallowing[14].

5.1.3. Stomach

The stomach serves as a temporary storage site for feed, facilitating both chemical and mechanical digestion. It is divided into regions, including the cardia, fundus, corpus, and antrum. In ruminants, the stomach comprises four compartments: the rumen, reticulum, omasum, and abomasum, each with specialized roles such as fermentation and enzymatic breakdown. The gastric glands in the stomach secrete hydrochloric acid, pepsinogen, and mucous to aid digestion[14].

5.1.4. Small intestine

The small intestine is the primary site for nutrient absorption, consisting of three parts: the duodenum, jejunum, and ileum. It features a mucosal layer with villi and microvilli that amplify its surface area, facilitating efficient absorption. Pancreatic enzymes and bile enter the duodenum to assist in the digestion of carbohydrates, proteins, and lipids[14].

5.1.5. Large intestine

The large intestine, comprising the cecum and colon, is involved in water absorption and fermentation of undigested food. In herbivores, the cecum and colon are well-developed for microbial fermentation, producing volatile fatty acids as energy sources. In carnivores, the large intestine plays a lesser role in digestion[14].

5.1.6. Accessory glands

Accessory glands, including salivary glands, the pancreas, and the liver, contribute to digestion by producing enzymes, bile, and other secretions. Saliva initiates carbohydrate digestion, while bile emulsifies fats, and pancreatic enzymes break down macronutrients in the small intestine[14].

5.2. Types of mammalian digestive systems

5.2.1. Monogastric digestive system: Carnivorous mammals, such as felines, possess a single-chambered stomach. Their digestive tracts are relatively short and straightforward, efficiently processing protein-rich diets. The cecum in these animals is either absent or reduced, reflecting their limited need to digest fibrous plant material[15,16].

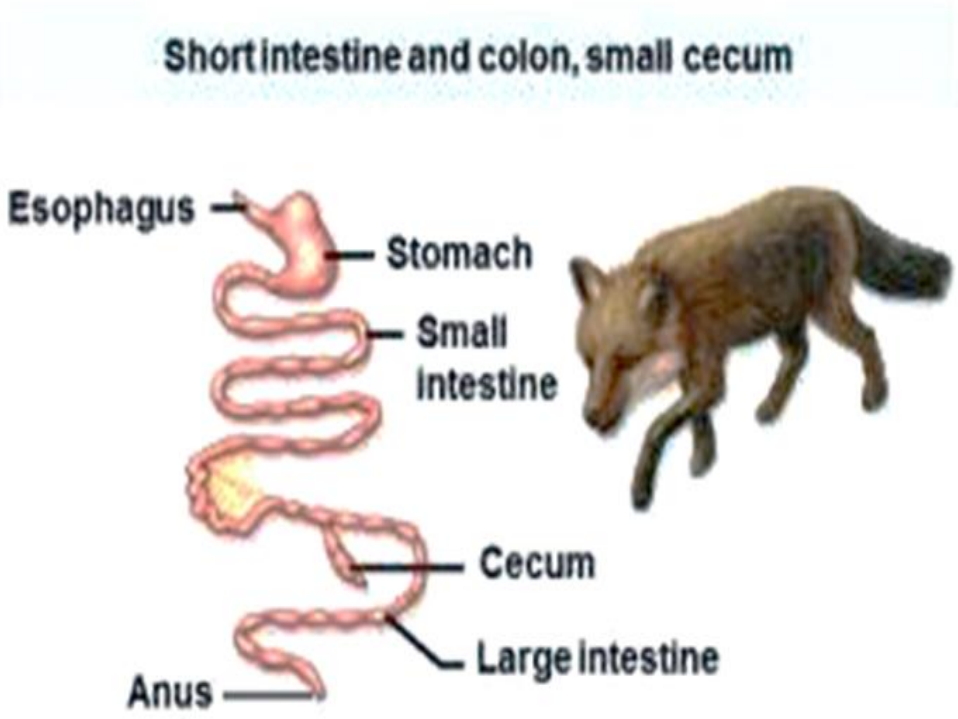


Figure 7. Carnivore digestive system.
(https://www.accessscience.com/highwire/markup/item_fulltext/370720)

5.2.2. Ruminant digestive system: Herbivorous mammals like cattle, sheep, and deer have evolved complex, multi-chambered stomachs to break down cellulose-rich plant matter. Their stomachs typically consist of four compartments: the rumen, reticulum, omasum, and abomasum. This specialized system allows for microbial fermentation, enabling the digestion of tough plant fibers[15,16].

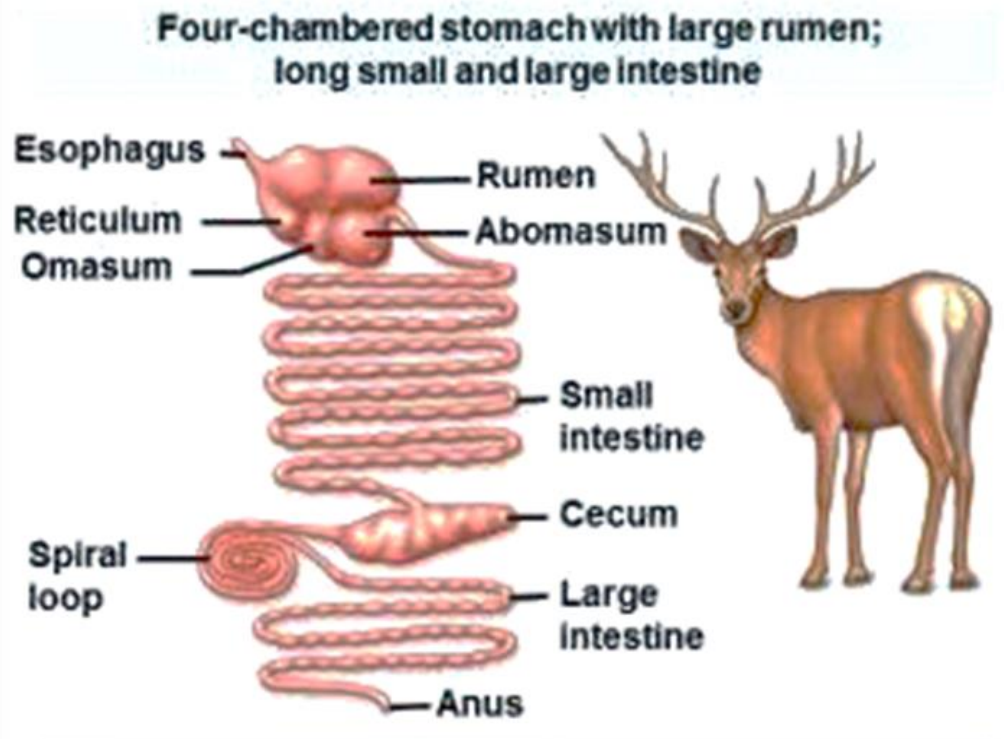


Figure 8. Ruminant herbivore digestive system.
(https://www.accessscience.com/highwire/markup/item_fulltext/370720)

5.2.3. Hindgut fermenters: Some herbivores, such as horses and rabbits, utilize a different strategy. They have an enlarged cecum and colon where fermentation of plant material occurs. This adaptation allows them to extract nutrients from fibrous diets, albeit less efficiently than ruminants[15,16].

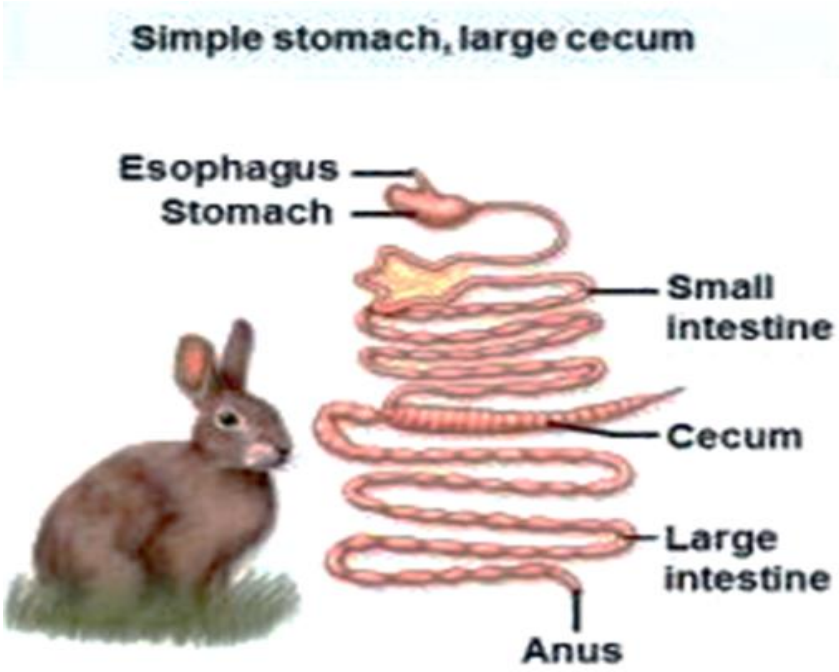


Figure 9. Non-ruminant herbivore digestive system.
(https://www.accessscience.com/highwire/markup/item_fulltext/370720)

6. Respiratory system

The mammalian respiratory system is a complex network of organs and structures responsible for the vital process of gas exchange, supplying oxygen to the body and expelling carbon dioxide. This system is typically divided into the upper respiratory tract, lower respiratory tract and the diaphragm (the primary muscle involved in respiration).

6.1. Upper respiratory tract

The upper respiratory tract of mammals consists of several key structures that facilitate the intake and initial processing of air. These include the nose and nasal cavity, the pharynx and the larynx[17,18].

The nose and nasal cavity serve as the primary entry point for inhaled air. Lined with mucous membranes and cilia, these structures warm, humidify and filter the air, trapping particulates and pathogens to protect the lower respiratory tract[17,18].

The pharynx, or throat, is a muscular conduit that connects the nasal cavity to the larynx and esophagus. It plays a dual role in the respiratory and digestive systems, directing air to the larynx and preventing food from entering the airway during swallowing[17,18].

The larynx, commonly known as the voice box, is located just below the pharynx. It contains the vocal cords and is essential for vocalization. The larynx also acts as a protective mechanism, closing during swallowing to prevent food and fluid from being aspirated into the lower respiratory tract[17,18].

Together, these components of the upper respiratory tract condition incoming air and serve as a defense mechanism against airborne pathogens and particulates, ensuring that the air entering the lungs is clean, warm and moist[17,18].

6.2. Lower respiratory system

The lower respiratory tract in mammals consists of the trachea, bronchi, bronchioles and alveoli, which together facilitate the passage of air into the lungs and the exchange of gases essential for respiration[17,18].

The trachea, or windpipe, is a cartilaginous tube that extends from the larynx into the chest cavity and serves as the main airway. It bifurcates into the right and left primary bronchi, each entering a lung[17,18].

Within the lung, the bronchi further subdivide into secondary and tertiary bronchi, forming a branching network that ensures air distribution throughout the lung tissue. These bronchi are supported by cartilage and smooth muscle to maintain airway patency[17,18].

The bronchi continue to branch into smaller bronchioles, which lack cartilaginous support and are mainly composed of smooth muscle and elastic fibers. This structure allows the bronchioles to regulate airflow by constricting and dilating, directing air to the regions of the lung where gas exchange is most efficient[17,18].

At the terminal ends of the bronchioles are clusters of alveoli, tiny, thin-walled sac-like structures that facilitate the diffusion of oxygen into the bloodstream and the removal of carbon dioxide from the blood. The large surface area and rich capillary networks of the alveoli are essential for efficient gas exchange to support the metabolic needs of the body[17,18].

6.3. Diaphragm

In most mammals, the respiratory system works in a similar way to humans, with the diaphragm playing a key role in controlling airflow. The diaphragm is a thin muscle that moves up and down to change the size of the lungs, helping air to move in and out. When the diaphragm

contracts, it flattens and moves downwards, increasing the space in the chest cavity and allowing the lungs to expand and fill with air. When it relaxes, it moves upwards, reducing the space in the chest cavity and helping to push air out of the lungs[19].

The movement of air is also affected by the difference in pressure between the chest and the outside atmosphere. Air flows from areas of higher pressure to areas of lower pressure, so if the pressure inside the lungs is lower than the outside air, air will flow in, and if it's higher, air will flow out[19].

Depending on factors such as altitude and environmental conditions, mammals may breathe through their mouths or noses. For example, at higher altitudes where the air is thinner, mammals may adjust their breathing to ensure they get enough oxygen[19].

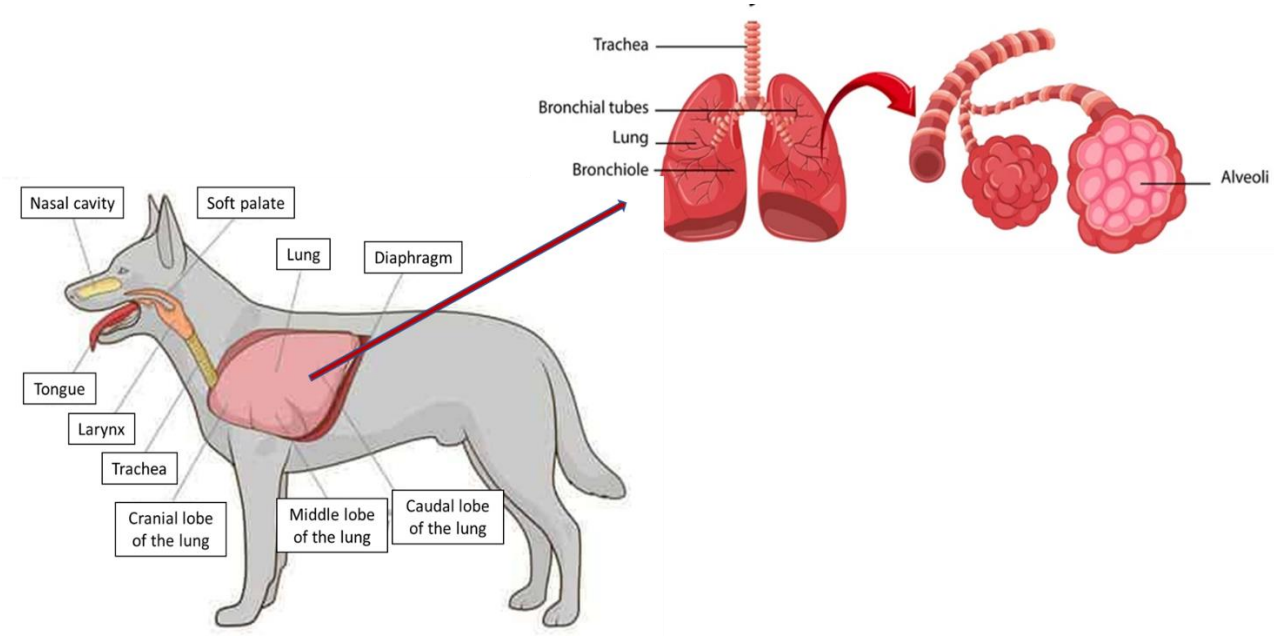


Figure 10: Respiratory system of mammals (Dog).
(https://www.shutterstock.com/fr/image-vector/respiratory-system-dog-vector-illustration-306525956)

7. Circulatory system

7.1. Heart

The mammalian heart is a vital muscular organ responsible for pumping blood throughout the body, delivering oxygen and nutrients to the tissues and removing waste products. It consists

of four chambers: two upper atria and two lower ventricles. This four-chamber structure allows complete separation of oxygen-rich and oxygen-poor blood, facilitating efficient circulation[20].

The walls of the heart are made up of three layers: the outer epicardium, the middle myocardium and the inner endocardium. The myocardium is responsible for the contractile force that propels the blood[20].

Valves between the chambers ensure unidirectional blood flow, preventing backflow and maintaining efficient circulation. The heart works through a coordinated sequence of contraction (systole) and relaxation (diastole), known as the cardiac cycle, which facilitates the continuous movement of blood to the lungs for oxygenation and to the rest of the body to meet metabolic needs[20].

7.2. Blood vessels

In mammals, the circulatory system consists of a complex network of blood vessels, arteries, veins and capillaries, each with different structures and functions that are essential for maintaining physiological balance[21].

Arteries are robust, elastic vessels that carry blood away from the heart. The main artery, the aorta, branches into larger arteries that carry oxygen-rich blood to different organs and tissues. Their thick muscular walls enable the arteries to withstand and regulate the high pressure created by the heart's contractions, ensuring efficient blood flow throughout the body[21].

Veins are vessels that carry oxygen-depleted blood back to the heart. They have thinner walls than arteries and often contain valves that prevent the blood from flowing backwards, allowing it to return at a lower pressure. This structural adaptation is essential to maintain unidirectional blood flow to the heart[21].

Capillaries are microscopic vessels that form extensive networks between arteries and veins. Their thin walls, made up of a single layer of endothelial cells, facilitate the exchange of oxygen, nutrients and waste products between the blood and surrounding tissues. This exchange is essential for cellular metabolism and overall homeostasis[21].

The coordinated function of arteries, veins and capillaries ensures efficient circulation, delivering essential substances to cells and removing metabolic waste to maintain the health and functionality of the mammalian organism[21].

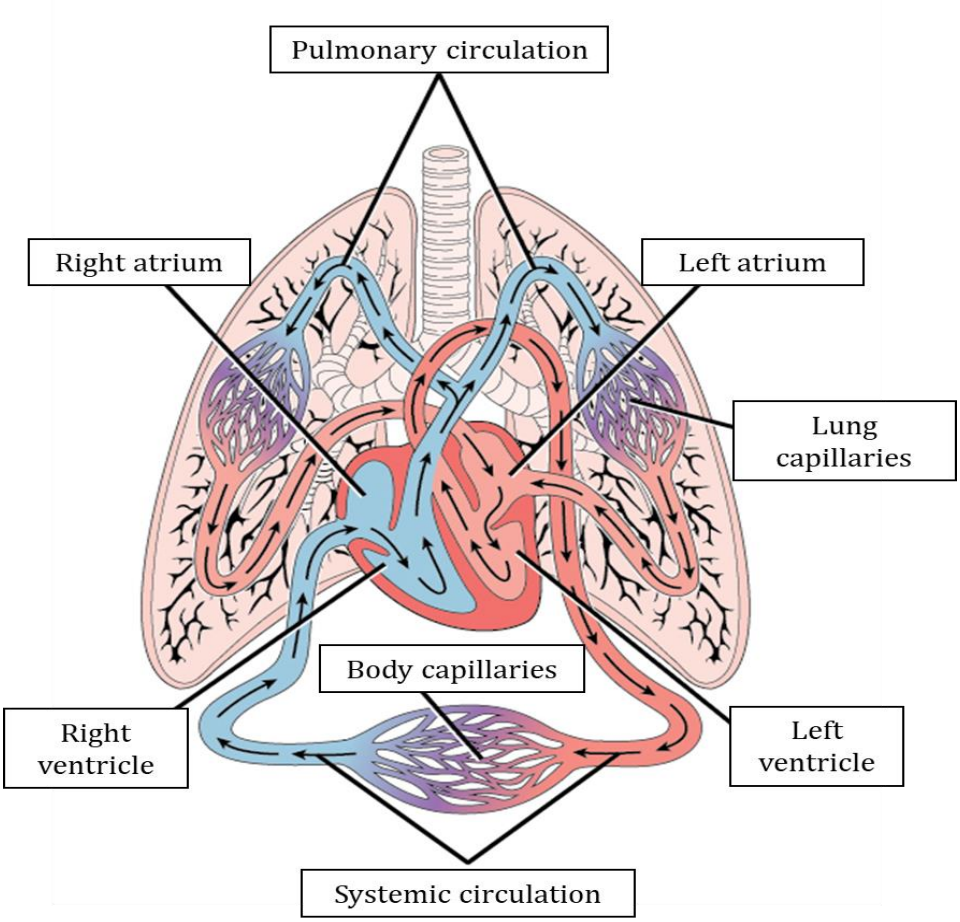


Figure 11. Circulatory system of mammals (https://www.theexpertta.com/book-files/OpenStaxBio2e/Chapter%2040%20-%20The%20Circulatory%20System.pdf)

8. Lymphatic system

The mammalian lymphatic system is a complex network that plays a crucial role in maintaining fluid balance, supporting the immune system and facilitating the absorption of dietary fats. Its main components include:

8.1. Lymphatic capillaries: These are microscopic, blind-ended vessels that originate in the tissues. They collect excess interstitial fluid, which contains proteins and waste products, from the spaces between cells. The unique structure of their overlapping endothelial cells allows interstitial fluid to enter but prevents it from leaving the tissue[22,23].

8.2. Lymphatic vessels: Lymphatic capillaries join to form larger lymphatic vessels that run parallel to the veins. These vessels carry lymph, a clear, watery fluid containing

lymphocytes, to the heart. Valves in these vessels ensure unidirectional flow, preventing backflow and facilitating the movement of lymph through the system[22,23].

8.3. Lymph nodes: Located along the pathways of the lymph vessels, lymph nodes are small, bean-shaped structures that filter lymph. They trap pathogens, foreign particles and cancer cells, and are sites where lymphocytes can mount immune responses. This filtration process is essential to prevent the spread of infection and disease[22,23].

8.4. Specialized lymphatic organs: These include the tonsils, thymus and spleen. The tonsils are involved in the defense against inhaled or ingested pathogens. The thymus matures T lymphocytes, which play a critical role in adaptive immunity. The spleen filters blood, removing old or damaged red blood cells and pathogens, and also acts as a reservoir for blood[22,23].

8.5. Lymph and interstitial fluid: Lymph is the clear, watery fluid found in the lymphatic vessels and is rich in lymphocytes. Interstitial fluid fills the spaces around cells, providing them with nutrients and a means of removing waste. Excess interstitial fluid is collected by lymphatic capillaries and becomes lymph, which is then transported back into the bloodstream, maintaining fluid balance within the body[22,23].

9. Excretory system

The excretory system in animals is responsible for removing waste products from the body, helping to maintain internal balance and prevent damage. Its main function is to filter out waste produced by cellular activity or taken in from the environment.

9.1. Anatomy:

The urinary system consists of several main components:

9.1.1. Kidneys: These are paired organs located on either side of the vertebral column and attached to the abdominal wall. Each kidney is covered by a connective tissue capsule and contains a renal cortex (the outer layer) and a medulla (the inner part). The medulla contains cone-shaped structures called renal pyramids[24,25].

9.1.2. Nephrons: The functional units of the kidneys, each nephron contains a renal corpuscle (where blood filtration begins) and a renal tubule (where filtered substances are processed). There are several parts to the renal tubule:

- ✓ Proximal tubule: The first segment, divided into convoluted and straight sections.
- ✓ Intermediate tubule: Contains descending and ascending regions.
- ✓ Distal tubule: Also divided into convoluted and straight sections.
- ✓ Connecting Tubule: Connects to the collecting duct.

The straight portions of the proximal and distal tubules, together with the intermediate tubule, form the loop of Henle[24,25].

9.1.3. Collecting ducts: These ducts collect urine from several nephrons and transport it to the renal pelvis[25].

9.1.4. Renal pelvis: A funnel-shaped structure that collects urine from the collecting ducts and directs it to the ureters[25].

9.1.5. Ureters: Tubes that carry urine from the kidneys to the bladder[25].

9.1.6. Urinary bladder: A storage organ that holds urine until it is ready to be expelled from the body[25].

9.1.7. Urethra: The tube through which urine is excreted from the body[25].

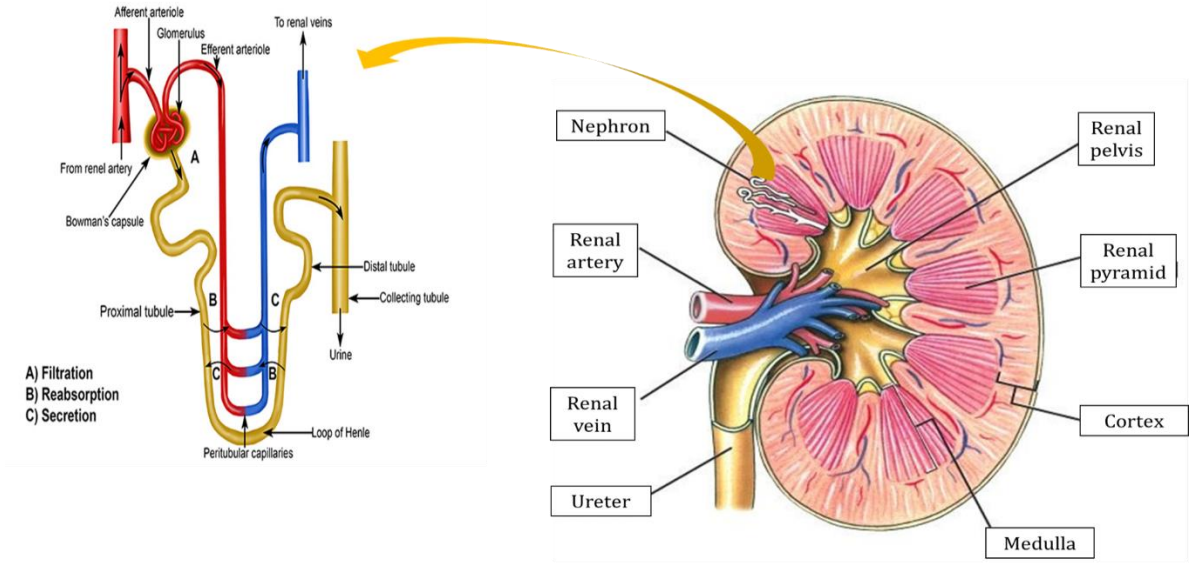


Figure 12. Anatomy of mammalian kidney.
(https://mammothmemory.net/biology/organs-and-systems/kidneys-the-renal-system/what-a-nephron-looks-like-up-close.html)

9.2. Characteristics

The kidneys receive blood from the renal artery, which branches into smaller arterioles that lead to the glomeruli (tiny capillary networks). After filtration, the blood exits through the efferent arterioles, which form a network of capillaries around the nephron. These capillaries eventually merge into veins that return the blood to the renal vein[26,27].

The walls of the urinary tract, except for the medial and distal portions of the urethra, are lined with a mucous membrane consisting of a transitional epithelium (urothelium) and underlying connective tissue. This epithelium adapts to changes in volume, especially in the bladder. Beneath the mucosa is a smooth muscle layer, and the outermost layer is connective tissue known as the adventitia[26,27].

The urinary bladder serves as a reservoir for urine, with the ureters from each kidney converging in it and the urethra emerging from it. The wall of the bladder can fold when empty and stretch when full[26,27].

There are sex differences in the urinary tract, especially in the urethra. In females, the urethra is a tube that is used only to expel urine from the body. In males, it also expels sperm and functions as a uroseminal duct. There are also differences in the type of epithelium that covers these ducts[26,27].

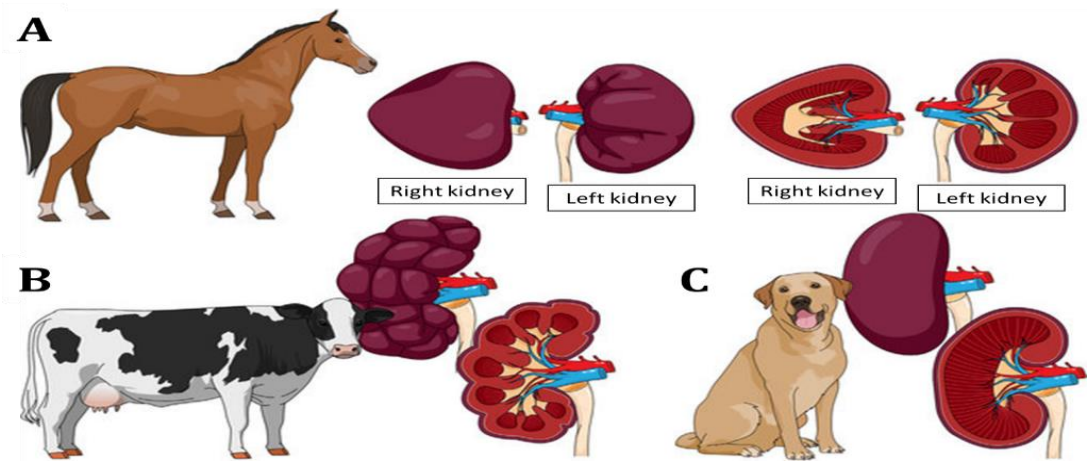


Figure 13. Species variation in mammalian kidneys: (A) equine with heart-shaped right and near bean-shaped left kidneys, (B) bovine kidneys with lobulated cortex but fused medulla, and, (C) canine bean-shaped kidneys with fused cortex and medulla. (https://www.researchgate.net/publication/346210329_The_struggle_to_equilibrate_outer_and_inner_milieus_Renal_evolution_revisited/figures?lo=1)

10. Reproductive system

In mammals, the reproductive system is an elaborate set of organs and structures dedicated to the production, nurturing, and delivery of offspring. This system is divided into male and female components, each with specialized anatomical features and functions.

10.1. Male reproductive system:

10.1.1. Testes: The primary male reproductive organs that produce sperm and secrete testosterone. In most mammals, the testes are located in the scrotum, which helps regulate the temperature optimal for sperm production. Notably, some mammals, such as elephants, have undescended testicles located deep within their body cavities near their kidneys[28,29].

10.1.2. Epididymis: A coiled tube adjacent to each testis where sperm mature and are stored until ejaculation[28,29].

10.1.3. Vas deferens: Ducts that carry mature sperm from the epididymis to the urethra in preparation for ejaculation[28,29].

10.1.4. Accessory glands: Including the seminal vesicles, prostate, and bulbourethral glands (Cowper's glands), these structures produce seminal fluid that nourishes and protects sperm during transport[28,29].

10.1.5. Penis: The organ responsible for delivering sperm to the female reproductive tract during copulation. It contains erectile tissues that become engorged with blood during sexual arousal, resulting in an erection. In many mammals, the penis contains a bone called the baculum, which provides structural support during copulation[28,29].

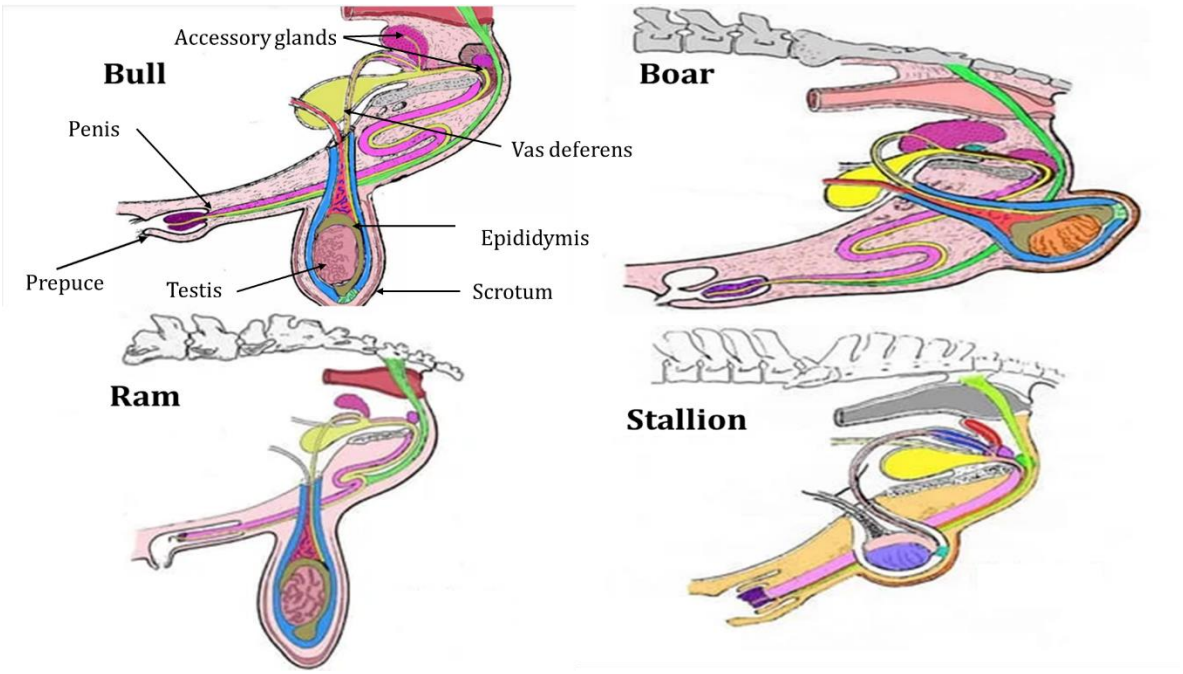


Figure 14. Comparative anatomy of the male reproductive system of mammals. (https://fr.slideshare.net/slideshow/comparative-anatomy-of-male-reproductive-system/143660443)

10.2. Female reproductive system

The female reproductive system in mammals consists of several key structures, each with specific functions essential for reproduction.

10.2.1. Ovaries: These are the primary female reproductive organs responsible for producing ova and secreting hormones such as estrogen and progesterone. Female mammals are born with a limited number of oocytes (immature egg cells) stored in the ovaries. Unlike males, who continuously produce sperm, females do not produce new oocysts after birth. The number of available oocysts decreases over time, affecting reproductive lifespan[30].

10.2.2. Fallopian tubes: These tubes carry oocysts from the ovaries to the uterus, where fertilization by sperm typically occurs[30].

10.2.3. Uterus: A muscular organ into which a fertilized oocysts implants and develops into a fetus. The structure of the uterus varies among mammalian species. For example, some species have a duplex uterus with two separate uterine horns,

while others have a simplex uterus with a single chamber. These anatomical differences are often related to litter size and reproductive strategies[30].

10.2.4. Cervix: The lower, narrow part of the uterus that opens into the vagina; it serves as a passageway for sperm to enter and for offspring to exit during birth[30].

10.2.5. Vagina: The canal that receives the penis during copulation and serves as the birth canal during delivery[30].

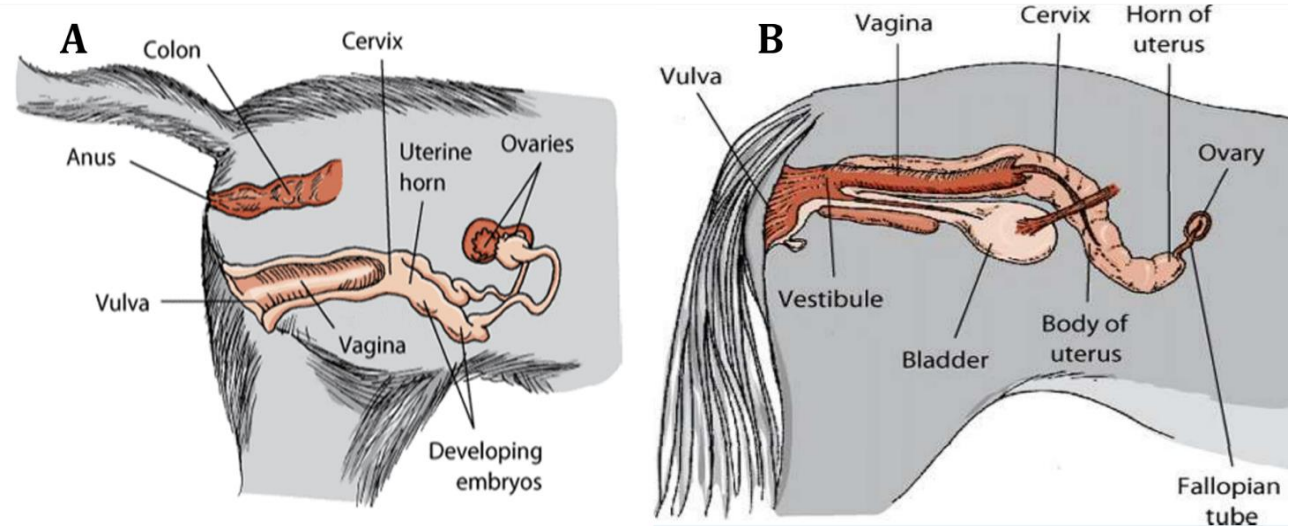


Figure 15. Female reproductive system: (A) Feline, (B) Equine. (https://www.basu.org.in/wp-content/uploads/2020/04/ANATOMY-OF-FEMALE-REPRODUCTIVE-ORGANS-IN-DOMESTIC-ANIMALS-1.pdf)

10.3. Reproductive characteristics:

10.3.1. Internal fertilization: Mammals engage in internal fertilization, in which sperm are deposited in the female reproductive tract and result in fertilization of the ovum[31].

10.3.2. Viviparity: Most mammals give birth to live young (viviparous), with the embryos developing in the mother's uterus and being nourished by a placenta. Exceptions include monotremes such as the platypus and echidna, which lay eggs but still have mammalian characteristics[31].

10.3.3. Estrous cycles: Mammals exhibit estrous cycles that regulate reproductive readiness. Species with estrous cycles experience periods of heightened sexual receptivity (estrus or "heat")[31].

10.3.4. Parental care: Mammals typically invest considerable time and resources in rearing their young, with mothers providing milk produced by the mammary glands to ensure the growth and development of their offspring. Beyond lactation, many mammalian species exhibit extensive parental care behaviors, including grooming, protection, and teaching survival skills. This investment enhances offspring survival and is a characteristic of mammalian reproductive success[31].

CHAPTER II:

CLASSIFICATION OF MAMMALS

Introduction

The classification of mammals is a fundamental aspect of zoology, facilitating the understanding of their evolutionary relationships, ecological roles, and behavioral diversity. Understanding the classification of mammals not only aids in species identification, but also provides insight into their evolutionary history and the adaptations that have allowed them to survive in diverse environments. Ongoing research continues to refine this classification and improve the understanding of mammalian biodiversity[32].

According to the classification proposed by McKenna and Bell[33], with substantial contributions by Wilson and Reeder[34], there are approximately 1229 genera and about 5420 recognized living species of mammals, with 5 to 12 new species described annually. When fossil mammals are included, there are over 5162 genera in 425 families, of which 79% of the genera and 71% of the families are extinct. In this second chapter, we will explore the classification of mammals, illustrated with photos representing each order, focusing on higher categories of mammals; extinct groups are not included.

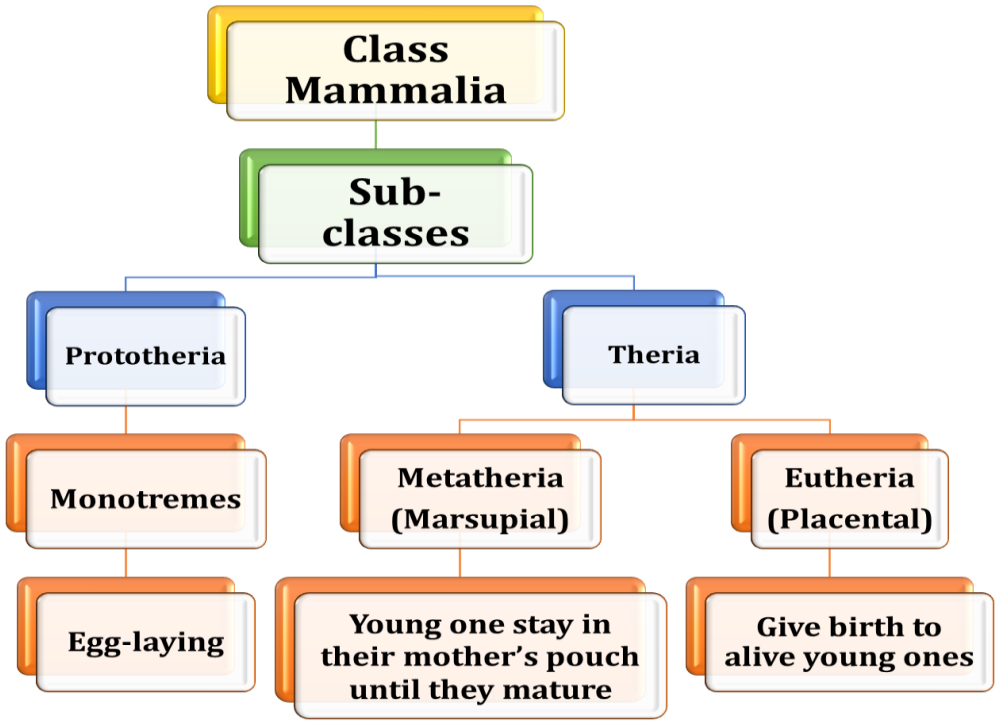


Figure 16. Simplified classification of mammals.

1. Subclass of Prototheria (monotremes, egg-laying mammals):

Five species are grouped into two orders; however, monotremes have traditionally been classified under a single order, Monotremata.

1.1. Order Tachyglossa (echidnas)

4 species in 1 family.

Commonly known as echidnas or spiny anteaters, these monotremes have unique morphological adaptations suited to their specialized diet and environment. Characterized by an elongated, slender snout that serves as both mouth and nostril, these monotremes possess strong, clawed limbs designed for digging. Their bodies are covered with a combination of coarse hairs and spines, providing excellent camouflage and protection. Tachyglossids are toothless, but have a long, sticky tongue for catching ants and termites[35].	

1.2. Order Platypoda (platypus)

1 species.

Commonly known as the platypus (*Ornithorhynchus anatinus*), the platypus has a distinctive morphology that reflects its semi-aquatic lifestyle and unique evolutionary lineage. Its streamlined body, approximately 38 to 60 cm in length, is covered with dense, waterproof fur that provides insulation and floatation. The most distinguishing feature of the platypus is its duck-like beak. The eyes and nostrils are located on the back, allowing the animal to see and breathe while the rest of the body remains submerged. The limbs are short and robust, with webbed forefeet that extend beyond the claws for efficient swimming[36].	

2. Subclass of Theria (live-bearing mammals)

2.1. Infraclass of Metatheria (Marsupials)

More than 330 species in 7 orders.

2.1.1. Order Diprotodontia (kangaroos, koalas, wombats, possums, and kin)

More than 140 species in 11 families.

Members of the order Diprotodontia are characterized by two distinctive morphological features: diprotodonty and syndactyly. Diprotodonty refers to the presence of a single pair of large, forward-facing lower incisors that dominate the lower jaw, an adaptation suited to their primarily herbivorous diet. Syndactyly involves the fusion of the second and third digits of their hind feet to the base of the claws, which aids in climbing and grooming[37].	

2.1.2. Order Dasyuromorphia (carnivorous marsupials)

About 70 species in 3 families,

Members of the order Dasyuromorphia exhibit distinctive morphological features adapted to their predatory lifestyle. They typically possess sharp, pointed teeth and well-developed canines for seizing and consuming prey. Their limbs are generally robust, with strong claws that facilitate hunting and, in some species, climbing. Body sizes vary widely within the order, ranging from the small dunnart to the large Tasmanian devil[38].	

2.1.3. Order Peramelemorphia (bandicoots and bilbies)

About 21 species in 3 families.

Members of the order Peramelemorphia, which includes bandicoots and bilbies, have distinctive morphological features adapted to their terrestrial, ground-dwelling lifestyle. They have compact bodies with relatively short tails, except for the larger bilby, which has a long, brush-like tail. Their necks are short, and they have elongated skulls with long, pointed snouts. The hind limbs are relatively long and exceptionally powerful, with the fourth toe being the largest. Members of this order have a unique rear-opening marsupium, unlike the forward-opening pouches of other marsupials[39].	

2.1.4. Order Notoryctemorphia (marsupial moles)

2 species in 1 family.

Members of the order Notoryctemorphia, known as marsupial moles, exhibit unique morphological adaptations suited to their subterranean lifestyle. They have streamlined, cylindrical bodies covered with dense, velvety fur that helps reduce friction while burrowing. Notably, they lack external ears and have vestigial, functionally blind eyes covered by a protective shield of skin that renders them effectively blind. Their elongated, shovel-like forelimbs are equipped with strong, curved claws that facilitate efficient digging and movement through loose sand. The hind limbs are shorter and less specialized, aiding in propulsion within the burrow[40].	

2.1.5. Order Microbiotheria (monito del monte)

1 species (*Dromiciops gliroides*).

The monito del monte (*Dromiciops gliroides*) resembles a mouse with a short rostrum and small, rounded ears. Its dense coat is brownish-gray on the dorsal side, with white patches on the shoulders and rump, and lighter on the ventral side, ranging from yellowish-white to pale gray. A distinctive feature is the pronounced black eye-rings, which enhance its night vision[41].	

2.1.6. Order Didelphimorphia (opossums)

About 90 species in 1 family.

Order Didelphimorphia exhibits a wide range of morphological adaptations suited to their diverse habitats and lifestyles. Opossums vary in size from the small Kalinowski's mouse opossum, measuring around 6 cm in body length, to the larger Virginia opossum, which can reach up to 55 cm. Their fur coloration ranges from gray to brown, often with white or black markings, providing camouflage in their environments. A distinctive feature of many opossums is their prehensile tail, which aids in grasping and balancing, especially in arboreal species[42].	

2.1.7. Order Paucituberculata (shrew or rat opossums)

6 species in 1 family.

Order Paucituberculata, commonly known as shrew opossums. These animals typically range from 9 to 14 cm in length and have slender limbs, long pointed snouts, and slender, hairy tails. Their fur is generally grayish-brown, which provides camouflage in their forest and grassland habitats. They have small, rounded eyes and rely heavily on their keen sense of hearing and long, sensitive whiskers to locate prey, as their vision is relatively poor. Primarily nocturnal and largely carnivorous, they actively hunt insects, earthworms, and small vertebrates during the early evening and night[43].	

2.2. Infraclass of Eutheria (placental mammals)

More than 5,000 species in 20 orders.

2.2.1. Order Rodentia (rodents)

Nearly 2,300 species in 30 families.

Order Rodentia, largest order of mammals, characterized by a single pair of continuously growing incisors in each jaw, adapted for gnawing. Rodents range in size from 6 cm to 134 cm long. Their fur coloration varies widely, providing camouflage. Many species have strong, dexterous forelimbs for digging or manipulating food, and some have prehensile tails for balance and climbing. While most rodents are terrestrial, some have adapted to arboreal, fossorial, or even aquatic lifestyles, demonstrating their remarkable ecological diversity[44].	

2.2.2. Order Chiroptera (bats)

More than 1,100 species in 18 families.

The order Chiroptera is the second largest order of mammals. Bats range in size from the tiny bumblebee bat, with a wingspan of about 15 cm, to the large flying foxes, whose wingspans can reach 1.7 meters. Their wing structure consists of elongated fingers covered by a thin membrane called the patagium, which allows for remarkable maneuverability in flight. Bats are often divided into two main groups: Megachiroptera, commonly known as fruit bats or flying foxes, typica, Microchiroptera, or echolocating bats[45].	

2.2.3. Order Soricomorpha (shrews, moles, and kin)

About 430 species in 4 families.

The order Soricomorpha, includes small insectivorous mammals such as shrews, moles, and solenodons. These animals typically have elongated, pointed snouts and small eyes, adaptations suited to their burrowing and nocturnal lifestyle. Shrews are generally small and have sharp, spike-like teeth, while moles have strong, spade-like forelimbs for digging. Solenodons are characterized by their elongated snout and venomous saliva. Despite their size, members of this order play an important ecological role as insect predators[46].	

2.2.4. Order Afrosoricida (golden moles and tenrecs)

About 50 species in 2 families.

The order Afrosoricida includes two distinct families of small mammals: golden moles (Chrysochloridae) and tenrecs (Tenrecidae). Golden moles are burrowing animals native to sub-Saharan Africa, characterized by their simple bodies, reduced or absent external eyes, and specialized limbs adapted for digging. Tenrecs, found primarily in Madagascar, exhibit a remarkable variety of forms and ecological niches, with some species resembling hedgehogs, shrews, or otters. The morphological diversity is particularly evident in the shape of their skulls, which varies considerably between species[47].	

2.2.5. Order Erinaceomorpha (hedgehogs)

24 species in 1 family.

Erinaceomorpha, traditionally known as an order, includes the family Erinaceidae, which includes hedgehogs and gymnura (also known as moon mice). These small to medium-sized mammals are characterized by a long snout, a short tail, and, in the case of hedgehogs, a covering of modified hair that forms protective spines on the upper body and sides. Gymnura, on the other hand, lack these spines and have thick fur. Erinaceidae are omnivores, feeding on insects, earthworms, small vertebrates, fruits, and seeds. They inhabit diverse environments in Africa, Eurasia, and Southeast Asia[48].	

2.2.6. Order Primates (apes, monkeys, lemurs, and kin)

About 375 species in 15 families.

The order Primates includes a diverse group of mammals, including lemurs, tarsiers, monkeys, and great apes. Primates are characterized by features such as a large brain relative to body size, forward-facing eyes for stereoscopic vision, and flexible limbs with hands and feet. These adaptations facilitate complex behaviors and arboreal lifestyles. Primates inhabit diverse environments, primarily in the tropical and subtropical regions of Africa, Madagascar, Asia, and Central and South America. Their diet is varied, including fruits, leaves, insects, and small animals, reflecting their adaptability and ecological diversity[49].	

2.2.7. Order Artiodactyla (even-toed hoofed ungulates)

About 240 species in 10 families, including giraffes, camels, deer, cattle, pigs, sheep, goats, and kin.

The order Artiodactyla, commonly known as ungulates, includes species such as pigs, hippos, camels, deer, giraffes, antelopes, sheep, goats, and cattle. They are characterized by the structure of their limbs with an even number of toes, with the third and fourth toes bearing the animal's weight. Many species have complex multi-chambered stomachs that facilitate the digestion of plants through fermentation. This adaptation is particularly advanced in ruminants, a subgroup of artiodactyls which includes cattle, deer, and giraffes. Their habitats are diverse, ranging from forests and grasslands to deserts and aquatic ecosystem regions[50].	

2.2.8. Order Cetacea (whales, dolphins, and porpoises)

More than 80 species in 11 families.

Cetacea, an order of entirely aquatic mammals, include whales, dolphins, and porpoises. These animals have a highly specialized morphology adapted to life in water. Their simple, spindle-shaped bodies reduce drag, allowing for efficient swimming. The forelimbs have evolved into flippers, while the hindlimbs are absent, reflecting their complete adaptation to an aquatic existence. Instead, propulsion is achieved using a horizontally flattened tail fin. The skin is smooth and often hairless, which minimizes water resistance[51].	

2.2.9. Order Perissodactyla (odd-toed hoofed ungulates)

17 species in 3 families, including horses, rhinoceroses and tapirs.

The order Perissodactyls includes the ungulates, which means they walk on the end bones of their feet, which are enclosed in enlarged claws that form hooves. Members of this order usually have either one toe, as in horses, or three toes, as in tapirs and rhinoceroses. These mammals are generally medium to large in size. Perissodactyls are hindgut fermenters, having a digestive system adapted to break down fibrous plant materials in a specialized stomach and intestine.This adaptation enables them to adapt well to a herbivorous diet[52].	

2.2.10. Order Hyracoidea (hyraxes)

4 species in 1 family.

The order Hyracoidea includes small herbivorous mammals native to Africa and the Middle East. They are the only members of the family Procaviidae. Hyraxes are round, furry animals with short tails, usually 30 to 70 cm long and 2 to 5 kg in weight.Despite their similar appearance to rodents, they are more closely related to elephants and sirenians[53].	

2.2.11. Order Sirenia (manatees and dugongs)

5 species in 2 families.

Sirenia, commonly known as sea cows, is an order of fully aquatic, herbivorous mammals that includes manatees and dugongs. They are characterized by large, fusiform bodies that streamline movement through water. They possess paddle-like forelimbs and lack hind limbs, with a horizontally flattened tail fluke aiding in propulsion. Their dense bones act as ballast, countering buoyancy and facilitating bottom-feeding on seagrasses. They have a thin layer of blubber, making them sensitive to temperature fluctuations. Their nostrils are positioned on top of their snouts, equipped with valves that close when submerged, enabling efficient respiration at the water's surface[54].	

2.2.12. Order Proboscidea (elephants)

3 species in 1 family.

The order Proboscidea, which includes modern elephants and their extinct relatives such as mammoths and mastodons, is characterized by distinctive morphological features. Members of this order are large terrestrial mammals with a strong, column-like structure adapted to support their massive bodies. Their most prominent feature is the elongated proboscis, an extension of the upper lip and nose, used for feeding, communication, and manipulating objects. They also have large, curved tusks, which are elongated upper incisor teeth, and relatively thick, wrinkled skin that provides protection[55].	

2.2.13. Order Tubulidentata (aardvark)

1 species (*Orycteropus afer*).

The order Tubulidentata includes only one extant species, the *Orycteropus afer*, which is distinguished by unique morphological characteristics. Cape aardvarks are medium-sized nocturnal mammals with a stocky body, an arched back and an elongated head ending in a narrow, rounded snout capable of closing the nostrils. Its limbs are of medium length, each ending in tips equipped with strong shovel-shaped claws suitable for efficient digging. A distinctive feature of Cape aardvarks is their "tubular" tooth structure, without enamel and continuously growing throughout their lives[56].	

2.2.14. Order Carnivora (carnivores)

Nearly 290 species in 15 families.

The order Carnivora includes a wide range of mammals, including species such as cats, dogs, bears, and seals, united by distinct morphological features. A distinguishing feature is the presence of carnassial teeth, specialized blade-shaped premolars and molars, adapted for cutting meat, reflecting their ancestral carnivorous diet. Furthermore, the structure of the auditory bullae differs between the two suborders: the Feliformia species (such as cats) have two-chambered bladders, while the Caniformia species (such as dogs) have single-chambered or partially separate bladders[57].	

2.2.15. Order Lagomorpha (pikas and rabbits)

92 species in 3 families.

The order Lagomorpha includes small to medium-sized terrestrial herbivores, particularly rabbits, hares, and pikas, which are distinguished by unique morphological features. A key feature is their dental structure: they have four continuously growing upper incisors, two large ones in front and a smaller pair located directly behind, unlike rodents, which have only two. Lagomorphs typically have long, soft fur, large ears, and eyes set high on their heads, providing a wide field of vision. Their hind legs are long and muscular, adapted for jumping and fast movement, while the tail is rudimentary or short[58].	

2.2.16. Order Cingulata (armadillos)

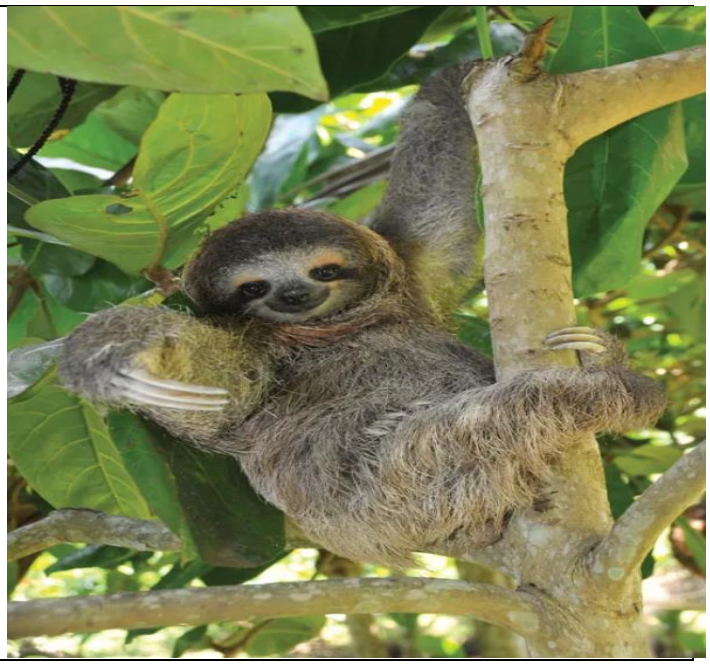
20 species in 1 family.

The order Cingulata comprises armored placental mammals known as armadillos, characterized by distinctive morphological features. A prominent feature is their protective armor, consisting of bony plates called osteoderms covered with a layer of keratin, which form a flexible but strong carapace that protects against predators. Armadillos have a cylindrical body with short legs; their forelimbs are equipped with powerful claws adapted for digging, facilitating their burrowing lifestyle. Their dentition is simplified, lacking incisors and canines, with pin-shaped molar teeth adapted to an omnivorous diet[59].

2.2.17. Order Pilosa (anteaters and sloths)

10 species in 4 families.

The order Pilosa, native to the Americas, includes two extant suborders: Folivora, which includes sloths, and Vermilingua, which includes anteaters. Sloths have long, curved claws and a low metabolic rate, making them adapted to an arboreal lifestyle. They lack incisors and canines, with molars adapted for grinding leaves, and are primarily arboreal, hanging from trees. Anteaters have long snouts and tongues adapted to consume ants and termites. They have no teeth at all, relying on their specialized tongues and saliva to process their food, and are primarily terrestrial, but also good swimmers[60].



2.2.18. Order Scandentia (tree shrews)

20 species in 2 families.

Members of the order Scandentia are small mammal species resembling squirrels, weighing between 45 and 50 g, found in the tropical forests of South and Southeast Asia. They have an elongated snout and a long bushy tail. Although they are insectivorous like true shrew, their diet is often dominated by fruits. Tree shrew exhibitunique parental behavior, with the female giving birth to one to three young, feeding them, and then leaving them in the nest while she searches for food. their maturation is fast, reaching independence in about a month and sexual maturity in four months[61].

2.2.19. Order Macroscelidea (elephant shrews)

15 species in 1 family.

The order Macroscelidea, commonly known as elephant shrews or sengis, includes small insectivorous mammals native to Africa. These animals are characterized by their elongated and flexible snout, which resembles the trunk of a miniature elephant and allows them to search for insects. They have slender, elongated limbs adapted for rapid and agile movement, often resembling those of a rodent in size and shape, with body lengths ranging from 10 to 30 cm. Macroscelidea have large eyes and ears, which allow them to have excellent vision and acute hearing, essential for detecting threats in their environment[62].

2.2.20. Order Pholidota (pangolins)

8 species in 1 family.

The order Pholidotas, which includes pangolins, is distinguished by its body covered with large overlapping keratin scales, which provide excellent protection against predators. Pangolins have an elongated, conical body, the size of which varies from 30 to 100 cm depending on the species. They have a long prehensile tail that helps them climb and maintain balance. Their small pointed head is equipped with a long, sticky tongue protruding beyond their mouth, which allows them to effectively consume ants and termites, their main diet. Pangolins have no teeth and must rely on their powerful abdominal muscles and the gravel they eat to grind their food. Their limbs are powerful and equipped with large claws, which they use to dig into termite or ant nests[63].	

For all the photographs of mammalian orders https://www.britannica.com/

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