1 Veterinary Physiology: Past, Present, and Future Perspective

C. G. Shashank, Pradip Kumar Das, and V. Sejian

Abstract

Physiology is the dynamic study of normal functions in a living system. It answers how the cells, organs, organ systems work and how it is integrated at the organism level. This chapter attempts to provide the readers with updated information on animal physiology evolution from past, present, and future perspectives. Physiology is the unit of biology and zoology, covering a range of subjects, including organs, morphology, cells, and biological compounds. Studying physiology has enormous practical applications ranging from cell generation and regeneration to cell death and apoptosis. This chapter gives a glimpse of the levels of structural organisation in animals. They start with the chemical levels, where atoms combine to form molecules, followed by cell levels, where molecules combine to form organelles. Subsequent integration is seen at the tissue level; similar cells and their surrounding material form tissues. Multiple tissues together include an organ, for instance, kidney, liver, heart, and many more. Furthermore, different organs synergistically work to form an organ system. For example, kidneys and urinary bladder together forms excretory system. To maintain normal body functions, a variety of systems work together to form a structural organisation and coordinate with each other in animals. Therefore, in order to practice veterinary medicine effectively, a basic understanding of animal normal physiology is required. The knowledge of physiology can be considered as the bedrock of the medicine.

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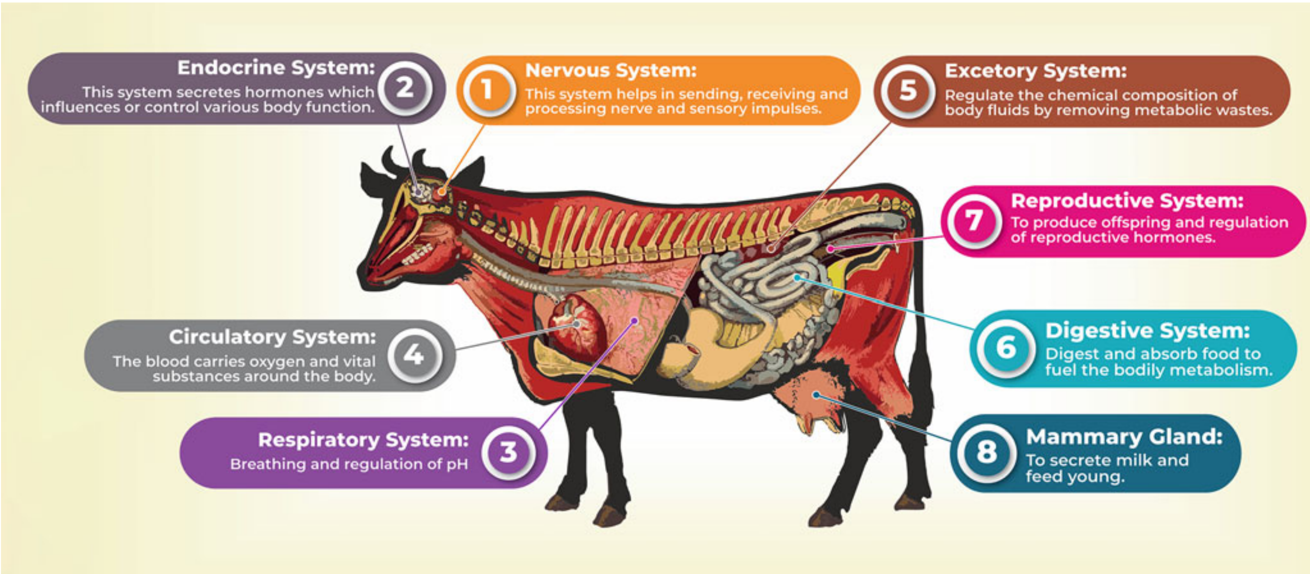
Graphical Abstract



The different systems and functions in dairy cattle

Keywords

Adaptation · Cell · Circulation · Digestion · Excretion · Respiration

Learning Objectives

- To understand the fundamentals of Physiology and its evolution from past to future.
- To appreciate how different organs and organs systems work within a set point for the survivability of animals.
- To witness the advances in the field of physiology.
- To comprehend the metabolic regulation within animals in the different environments.

1.1 Introduction to Veterinary Physiology

We share the earth with millions of wonderful living things. All uniquely adapted to their environments. Yet, despite our differences, we all have one thing in common, our survival. Everything we do relies on complex internal processes that, when working well, allow us to respond to the challenges of everyday life. The study of these mechanisms collectively is called Physiology—the science of life.

A physiologist aims to understand and explain the different physical and chemical dynamics responsible for life's origin, development, and progression at different systemic levels. The study of pathology and medicine is vital to comprehend the abnormal functioning of the body; therefore, it is essential to understand the physiology if one to decipher the mechanisms of disease.

Every life form existing on the earth, from the simple virus to the biggest mammal, has its functional physiological attributes. Thus, the ocean of physiology divides into different subcategories: embryology, cellular physiology, endocrinology, immunology, nutrition physiology, reproductive physiology, lactation physiology, and many more.

Veterinary physiology deals with exploring the structure and functioning of an animal's system and the biological processes by which it interacts with its environment. Animals are exposed to several different environments; probably, the environment presents the biggest challenge. A physiologist tries to examine and explain how biological processes function, adjust, and operate under various environmental conditions, further how homeostasis is achieved such that normal processes are integrated and regulated. For example, an animal's external environment is never constant, and it keeps changing. The change in temperature, availability of feed and water, fluctuations in gas concentrations, and many more may occur daily or at regular intervals may pose a challenge to the basic functioning of animals. To acclimatise and survive in these changing environments, animals need to modify their internal environment like bodily fluids, cellular functioning, endocrine systems, and so on. This continuous maintenance of the internal state is known as homeostasis. The function of most of the organs and associated systems is to maintain homeostasis besides its regular operation. Complete details and associations between different cells, organs, and systems will be explained in further chapters.

Here is the thing, every time animals take a breath, open their eyes, or take a step; a multitude of scientific forces is at play. Thankfully advances made by physiologists and associated scientific researchers in and around the lab provide core information for veterinarians to tackle various significant health challenges animals face today.

1.2 History

Different demographic regions have their history concerning veterinary medicine and physiology. The history of physiology and medicine in a tropical country like India, dating back to the early Vedic period, is fascinating. In Rigveda (2000–4000 BC), we can find fragments of evidence indicating the presence of literature on Veterinary Science, where physicians dealt with both animals and humans comprehensively. The veterinary sciences and animal husbandry practices have been mentioned in Atharvaveda too. Furthermore, in pieces of literature like Asva-Ayurveda: about horses; Gau-Ayurveda: about cows; Hasti-Ayurveda: about elephants and Shyenka-Ayurveda: about Hawks, preservation, and breeding practices are chronicled very specifically. Salihotra, regarded as the "Father of Veterinary Sciences" in India. Palkapya (700–400 BC) dealt with elephants' anatomy, physiology, and management in detail.

Subsequently, outside Asia, the biggest chunk of physiological research was conducted using animal models to understand human anatomy and physiology better. For example, Claudius Galenus (AD 129–circa 199) performed studies to learn more about the body's mechanisms by performing dissection and vivisection on nonhuman primates, such as Barbary apes, to establish the validity of his physiological theories. Ancient Greek physiological ideas, customs, and philosophies were advanced during the Medieval period by Ibn al-Nafis (1213–1288), who discovered and characterised the heart and lungs anatomy. His revolutionary work established the crucial relationship between lungs and the aeration of the blood. The first modern anatomy textbook was written by Andrea Vesalius (1514–1564). Blood flow and cardiac contractions and relaxations were demonstrated by William Harvey (1578–1657).

In the eighteenth century, two Dutch physicians, Hermann Boerhaave and Albrecht von Haller proposed bodily functions as physical and chemical processes. Further, during the nineteenth century, the pace catches up very rapidly. Mathias Schleiden and Theodor Schwann proposed "Cell theory". Claude Bernard (1813–1878) coined the term milieu interieur (internal environment), which refers to the preservation of the internal environment in living organisms regardless of its external environment, which was refined by Walter B. Cannon (1871–1945), who coined the word homeostasis.

Per Scholander (1905–1980) was a comparative physiologist who specialised in the physiological responses of animals to extreme temperatures, such as warm-blooded animals in a cold environment. George Bartholomew (1923–2006) officially founded the section on ecological physiology, where he coupled animal behaviour, physiology, and their interface with the environment to understand animals' adaptation better. Knut Schmidt-Nielsen (1915–2007) was also an expert on environmental physiology. His primary research concentrated on the adaptation of camels to desert conditions. He pointed out the moisture recapture mechanism in exhaled air, which accounts for nearly 60% of the reduction in water loss in camels compared to other animals. Additionally, many other physiologists have made substantial contributions to this huge ocean of knowledge known as physiology.

1.3 Importance of Veterinary Physiology

Veterinary physiology is widely regarded as a foundational discipline for comprehending the distinction between animals' well-being and disease conditions. From cell differentiation and regeneration to cell death and apoptosis, the study of physiology has immense practical applications. For instance, a veterinary physician who studies heart functioning and associated diseases, it is essential to understand the blood pumping mechanism from the heart and the pressures generated with it to transport red blood cells (RBC) throughout the body. In this book, we have discussed different systems and their functionality practically so that readers get creative notions about the application part associated with them.

To demonstrate the significance of physiology, we could use the example of wild animals in captivity. Wild animals are captured and brought to captivity for numerous reasons—conservation, research, the pet trade, and many more. Sudden exposure of wild animals to confinement has resulted in various physiological stresses, like elevated glucocorticoid hormone, fluctuations in respiration rate, heart rate, core body temperature, and skin temperature. While these are adaptive, if it persists chronically, it leads to physiological problems like weight loss, improper immune system functioning, and lowered fertility rate. A study reported that beluga whales had less thyroid hormone concentration when initially exposed to captivity and continued till 10 weeks of captivity (St Aubin and Geraci 1988). In the above context, the primary work of physiologists is to comprehend and quantify the cost these wild captive animals had to spare for survival. This research may aid in a better understanding of the challenges affecting animal health and the development of ameliorative techniques to enhance their well-being while in captivity.

To illustrate, introducing a female to the cage of male brown-headed cowbirds reduced plasma glucocorticoid production and boosted testicular regrowth and many more.

To summarise, veterinary physiology is a crucial discipline for comprehending:

1. The fundamental biology of all animals
2. Animal health and disease
3. Relation between physiology and ecology, in the present and future evolutionary period
4. The relationship between humans and animals in terms of disease transmission and prevention

Know More. . .. . .
First Cloned Animals Names
Cattle: Daisy; **Buffalo**: Samrupa; **Pashmina Goat**: Noori; **Dog**: Snoopy; **Camel**: Injaz; **Horse**: Prometea

1.4 Basic Living Unit of the Body: Cells

All animals are made up of a complex yet unique bunch of living units—cells (Fig. 1.1). It is the cell interconnectedness in living organisms that creates the beauty of complex systems. Each organ is a group of many different cells that are intercellularly supported through structures.

Interestingly, the surface membrane is a mere 70–100 Å thick (0.0000007–0.00001 mm). The average size of cells is around 10–100 μm, or 0.01–0.1 mm in diameter, denoting the fragile nature of the cell and membrane. This identification was made more accessible by discovering an electron microscope. Many intracellular organelles like the Golgi complex, endoplasmic reticulum, nucleus, mitochondria, vesicles, and many more organelles or structures were identified.

A typical animal cell consists of nucleus, a cell membrane, and cell cytoplasm. The nucleus is the structure that houses genetic information, generally referred to as DNA, and it controls the actions and the reactions of the cell. The cell membrane, the border of the cell, acts as the gatekeeper. It controls what enters and exits the cell and enables adjacent cells to stick to each other. The cytoplasm is where chemical reactions take place in cells.

Know More. . .. . .
Cells Are Self-destructive
No, this does not imply that cells self-destruct automatically. If a cell is injured or has DNA defects, it self-destructs to avoid interfering with other cells.

There are numerous distinct cell types, each with a unique set of capabilities. For instance, cattle maintain an average of 6.3×10^{12}/L RBCs, with the major purpose of carrying oxygen from the lungs to the respective tissues. At a rough guess, cattle might have around 105–420 trillion cells. One of a kind is nerve cells which have branched endings called dendrites. This is so they can communicate with lots of other nerve cells through electrical impulses. White blood cells (WBCs) enable animals to fight infections. Their distinctive lobed nucleus can be used to identify them. WBCs have a flexible cytoplasm so that they can engulf pathogens in a process called phagocytosis. Some other WBCs are specialised in producing antibodies, and it is these antibodies fight pathogens.

Though cells have different functions, essential physical characteristics are similar. For instance, in all cells, the reaction of oxygen with carbohydrates, fat, and protein produces the energy necessary for cell function. Additionally, the chemical mechanisms by which nutrients are converted to energy are

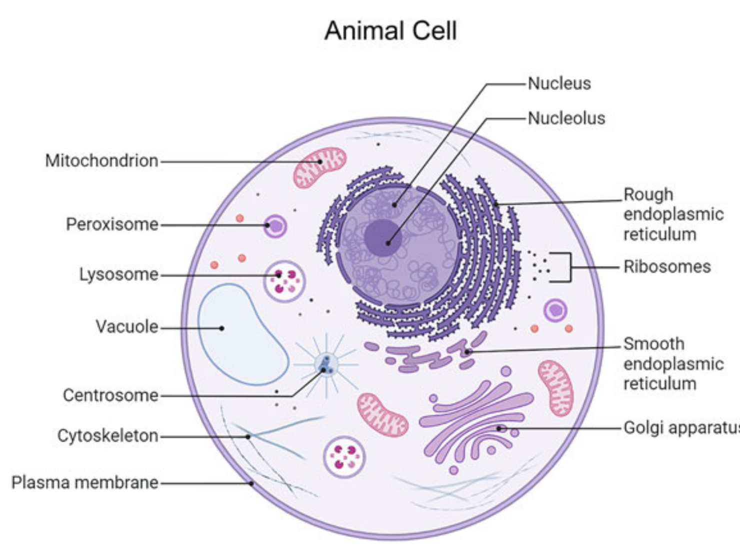


Fig. 1.1 Description of the typical mammalian cell and its components. (Courtesy: BioRender)

roughly comparable in all cells. All cells excrete the products of their chemical reactions into the adjoining fluids.

Those mentioned above are fundamental features of cells. With the improvements in technology, it is possible to generate an entire animal from a single cell using multiple techniques. For example, cattle cloning was done using the somatic cell nuclear transfer (SCNT) technique, one of the genetic engineering tools. Recently with advancements in designer nucleases, such as transcription activator-like effector nuclease (TALENs), zinc-finger nucleases (ZFNs), and clustered regularly interspaced short palindromic repeats/CRISPR-associated protein 9 (CRISPR/Cas9) made path-breaking discoveries that can create a designer offspring's, which will be beneficial to maintain elite lineage in animals. Concluding, with recent advancements in genetic engineering, one can anticipate that the agricultural and biomedical applications of genetically engineered animals that have been long envisioned will soon be recognised in the marketplace.

1.5 The Physiology of Integration

Integration is a broad term that refers to processes such as summarisation and coordination that result in incoherence and harmonious process. The term "integration" refers to combining sensory, endocrine, and central nervous system impulses to ensure the appropriate functioning of the animal. Whole animal integration consists of many systems but mainly nerve and endocrine cells, leading to smooth, coordinated movements.

1.5.1 Nervous System

The nervous system is essentially a massive, complex, body-wide communication system. To demonstrate, stimuli are relayed to the Central Nervous System (CNS) through sensory neurons; further detected by a receptor, which sends the electrical impulses along a sensory neuron to the CNS. The CNS then relays the message by motor neurons to effectors that respond, such as stimulating animals' legs to run when they are about to get hunted.

Nerve cells are known as neurons (the basic unit of the nervous system). The nervous system consists of two major systems: the central nervous system (CNS) and the peripheral nervous system (PNS). CNS comprises the brain and spinal cord, and it is rich with cell bodies (axons and dendrites) of neurons. Within CNS, there are three different types of neurons: sensory, intermediate or relay, and motor neurons. These specialised cells carry information as tiny electrical impulses and make up the nervous system. Sensory neurons carry signals from receptors to the spinal cord and then to the brain. For instance, the eyes send data to the brain about the environment. The intermediate or relay neurons carry messages from one part of the CNS to another and the motor neurons carry signals from the CNS to effectors. The PNS is a division of the nervous system that deals with all the nerves outside of the CNS. The complexes of nerves that make up the PNS are axons or bundles of axons from nerve cells or neurons. It ranges from microscopic to large size that can be easily visible to the human eye. Further divisions of PNS are the somatic nervous system (SNS), which controls voluntary movements like skeletal muscles, and the autonomic nervous system (ANS), which takes over the striated and non-striated muscles. All neurons have three main components; a cell body with a nucleus, dendron, and dendrites which are the neuron's inputs. They receive information from other neurons or the external environment and transfer it to the cell body, and other axons carry the signal away from the cell body. Nervous systems mainly consist of neurons and glial cells, connective tissue cells, and circulatory system cells.

Previously, these cells were identified through a simple microscope. Later internal structures were acknowledged through electron microscopy, and presently, different cross-section imaging technologies like functional magnetic resonance imaging (fMRI), computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET) have revolutionised neurology, where physiologists study the functioning of the nervous system. For example, common nervous neoplasia in dogs and cats are meningiomas and gliomas. These two neoplastic cells compress brain parenchyma. Demonstrating this neoplasia through MRI and CT scans is very reliable and easy compared to old techniques practised.

1.5.2 Endocrine System

Endocrine system, also known as the hormone system, comprises many tissues that regulate animals' internal environment by releasing a chemical substance called hormones into circulation to act on the target organ for the desired action. Endocrine tissues are typically ductless glands (e.g. pituitary, thyroid) that secrete hormones via capillaries that permeate the tissue (Fig. 1.2). These glands receive an abundant supply of blood. However, non-typical endocrine tissues contribute significant amounts of hormones to circulation, for example, secretion of the atrial natriuretic peptide from the heart, erythropoietin from the kidney, insulin-like growth factor from the liver leptin from fat.

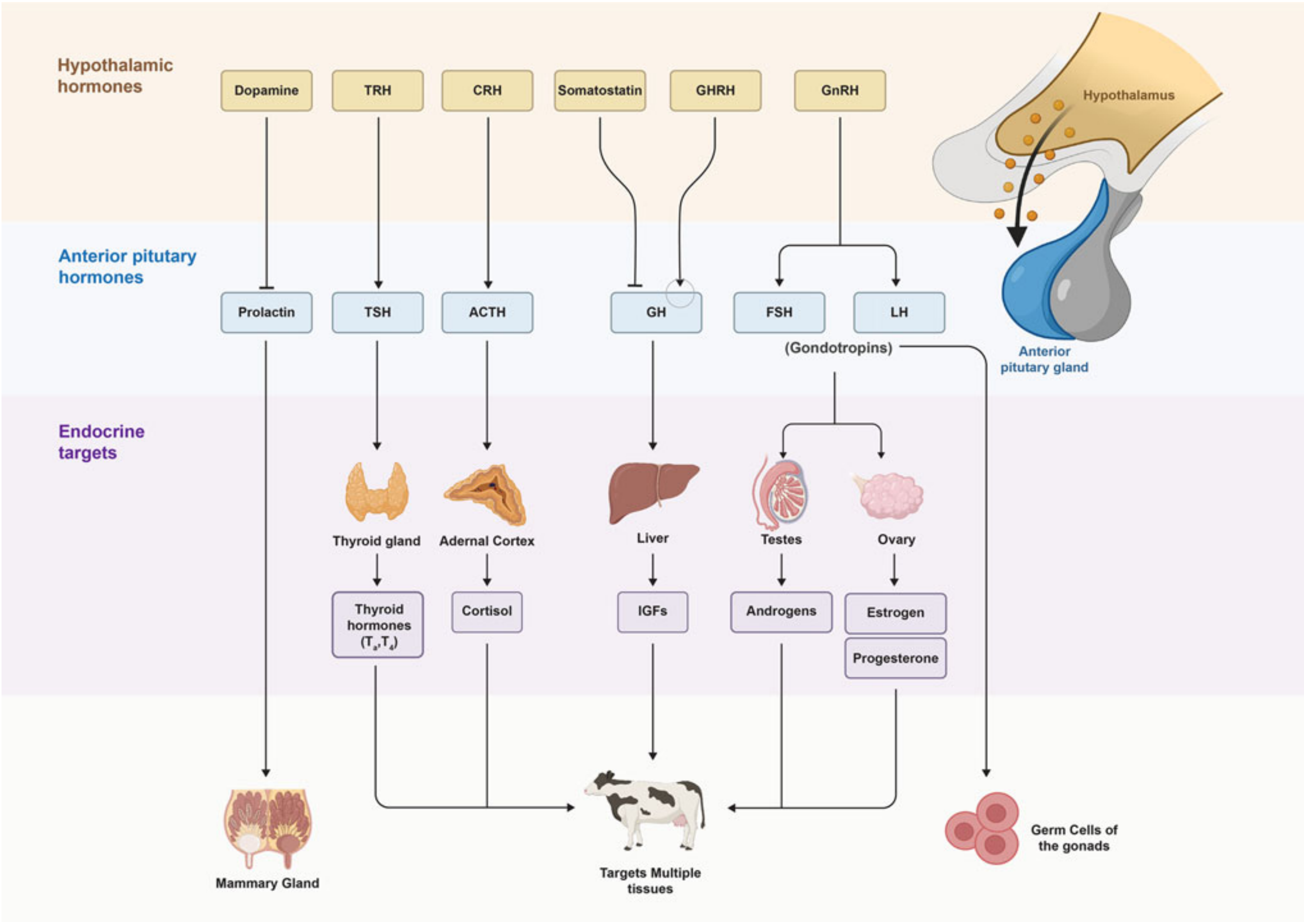


Fig. 1.2 Description of the complete endocrine system and the different constituents in cattle. (Courtesy: BioRender)

> **Know More. . . . .**
> **Fun Fact**
> Elephants breathe out an average of 310 L of air per minute

The endocrine system controls physiological processes like growth, metabolism, reproduction, behaviour, body regulation, development, fluid, and water balance to maintain homeostasis in most animals. For instance, cows during oestrous phase, various endocrine signals cause characteristic signs like frequent micturition, bellowing, swollen vulva, and mucus discharge. These signs act as visual signs to attract ox, leading towards promoting reproduction. Nevertheless, another class of hormones named pheromones is also responsible for the mentioned example. Pheromones are chemical signals that act within species produced within the animal and then released into the environment. Pheromones also influence physiological functions like the onset of puberty and oestrous.

Several hormones are secreted by the pituitary gland located right below the hypothalamus in the brain. According to the stimuli, the hypothalamus instructs the pituitary gland to secrete related hormones. The secreted hormones make their way via the bloodstream to the target organs. They either elicit a specific reaction directly or stimulate or cause the target organ to secrete hormones. We can think of this as a post office system. Hormones or posts must reach the correct target organs or addresses for the proper response to occur. For example, when hypothalamus detects low water levels in the blood, it signals the pituitary gland to release the antidiuretic hormone (ADH) into the bloodstream. ADH travels to the kidneys, the target organ, and causes water to be absorbed, so urine becomes more concentrated and decreases output. Water consumption elevates the water content in the blood, which subsequently causes the hypothalamus to instruct the pituitary gland to secrete less ADH. Less ADH means kidneys will absorb less water, causing urine to become less concentrated and increase output.

Presently, endocrinologists play around with different hormones to get the best and fast animal stocks to fulfil the global food demand. For example, hormones like androgens and oestrogen are implanted beneath the ear skin. These implants release growth promoters over time into the bloodstream. Animals attain growth much faster compared to traditional methods, thus filling the gap. Along with the development, we need to look into welfare too. Due to urbanisation, various chemicals accumulate in environments that act as hormone agonists or antagonists, finally disrupting hormonal imbalance, leading to the endocrine disruptor hypothesis. This condition is particularly harmful to aquatic, young, and unborn animals. However, the long-term impact of this on humans is still up for debate. Developments in endocrinology depend on emerging technologies like Omics and structural biology. Looking back, one might question them; will we ever fully comprehend how hormones act at the cellular level. The quick answer is: No. Our present understanding of endocrinology at any given time will influence future hormone research.

1.6 Exchange and Transport System

Imagine if animals took a couple of hours for the oxygen that they breathe to reach their cells. Well, if the giraffe relied on diffusion alone from oxygen to get to the tip of the head, by the time oxygen reaches cells would have died. This is why large multicellular organisms have developed specialised exchange surfaces like lungs, gills, digestive systems, and specialised transport systems like circulatory systems. These systems help animals to exchange gases and nutrients with the surroundings and transport them where they are needed within the body. As we all know, animals have smaller surface areas compared to large volumes. It is slightly inefficient at exchanging substances. To cope with that, how animals have progressed exchange services and short diffusion distances are mentioned in the below sections.

1.6.1 Respiratory System

The respiration system is a significant life-supporting system with many essential functions as gas exchange, oxygen supply to cells, maintaining the balance between gases, and pH in the body (Fig. 1.3). The respiratory system provides animals with oxygen and removes metabolic by-products such as carbon dioxide. Failure of the respiratory system is related to malfunction of various organ systems, with potentially fatal implications. For example, the COVID-19 pandemic during 2020 affected not only humans but animals too. Asiatic lions were found positive for COVID-19 in Hyderabad Zoo and Etawah Safari park, India, and mink farms in the Netherlands. A virus arrested the proper functioning of the lungs by compromising the immune status of the animals, which leads to further secondary complications, finally resulting in death.

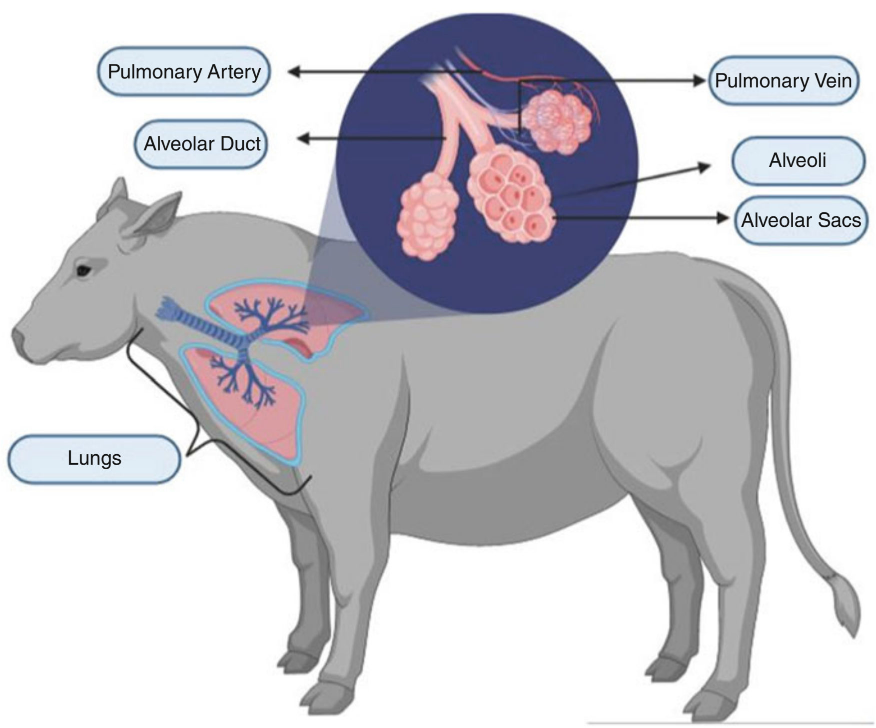


Fig. 1.3 Description of the respiratory system and its components in cattle. (Courtesy: BioRender)

Know More. . .. . .

Did You Know?

Lungfish have both gills and lungs. Many researchers even believe that lungfish might be the missing link between marine animals becoming land-dwellers.

Now the question is why cells produce carbon dioxide following oxygen consumption? Animal depends on mitochondrial respiration to supply ATP to perform normal cellular activities. To summarise the whole process, animals breathe in oxygen, and lungs load up this inspired oxygen (O_2) to red blood cells (RBC), which carries O_2 to cells. Cells absorb oxygen through diffusion, where mitochondrial respiration comes into action. Mitochondria oxidise the available carbohydrates, amino acids (AA), and fatty acids to produce ATP, resulting in CO_2 production. Produced CO_2 is transported back to the lungs through RBC, then the expiration of CO_2 from the lungs. On an outer look, it looks effortless. Still, if we dive deep, we can witness the impact of different factors like haemoglobin concentration, partial pressures of various gases, lungs pressure and movement of diaphragm concentration of alveoli, and many more. Unicellular organisms and aquatic animals may utilise diffusion gradients to drive gas exchange with the environment. In comparison, gaseous O_2 requires an additional step to cross the cell membrane in terrestrial animals.

A common thought might be, what about the respiration in aquatic animals! Wouldn't it catch your attention on mentioning, the exchange of gases in fish larvae is through the diffusion of gases across their body surfaces. Readers can appreciate complete comparative mechanisms in different species in detail in respective chapters.

Know More. . .. . .

Octopuses have three hearts. A blue whale's heart weighs about 400 pounds. A cheetah's heart rate can speed up to 250 beats per minute within seconds.

We know that the respiratory system is more than just lungs; it includes the nose, followed by the nasal cavity, pharynx, larynx, trachea, primary bronchus, secondary bronchus, tertiary bronchus, respiratory bronchiole, alveolar duct, alveolus, and diaphragm. But can you envision the design and fabrication of lungs outside the body? Yes, we are facing the future right in front of us. Bioengineered Lungs (BEL) is an exciting and rapidly progressing area in the veterinary biomedical field. It is an alternative for end-stage lung failures. Researchers are developing bronchial system circulation in non-immunosuppressed pigs to support BEL growth and animal survival after transplantation. Previously, researching and discovering medications for the treatment of respiratory disorders incurred very high variability and high costs. However, with the use of in silico and tissue-engineered lungs models, it is possible to understand various mechanical and biological variables that make in vivo research difficult. However, on the flip side, single-cell sequencing technologies, advancements in cellular and tissue imaging techniques, and improvements in tracking cell lineage systems have led to understanding the complex relationship between the respiratory system, cardiovascular system, and exchange of gases.

1.6.2 Circulatory System

The circulatory system works to transport oxygen and nutrients throughout the body while removing waste products such as carbon dioxide, urea, and many metabolic wastes at the same time frame (Fig. 1.4). The heart, blood vessels, and blood are the major components of the circulatory system. The circulatory system is divided into two circuits: the pulmonary and systemic. In the pulmonary circuit, deoxygenated blood is pumped from the heart to the lungs to become oxygenated. In contrast, this oxygenated blood returned to the heart is pumped to the rest of the body in the systemic circuit. Unlike other muscles in the body, the heart, a muscular organ, never tires and works very hard to ensure that blood reaches all parts from head to hoof.

Is blood always red? Wrong, blood comes in a variety of colours. It may be red in humans and other mammals, but an octopus, for example, has blue blood and oscillated eyes. Fish have completely clear blood, and in Papua New Guinea, they are green-blooded. The composition of blood is very simple yet extraordinary. Blood consists of red blood cells, white blood cells, platelets, and plasma. About 55% of the blood is the pale yellow sticky liquid found in animals called plasma. The plasma is mainly made up of water and proteins. Plasma carries nutrients, hormones, and proteins around the body. It contains about 92% water. About 45% of the blood is made up of RBCs. RBCs are tiny biconcave disc-shaped cells, also known as erythrocytes. Formation occurs in the bone marrow. It contains a special iron-containing protein called haemoglobin. Haemoglobin that makes the warm-blooded animal's blood red, the octopus, has a unique protein called haemocyanin, making their blood blue.

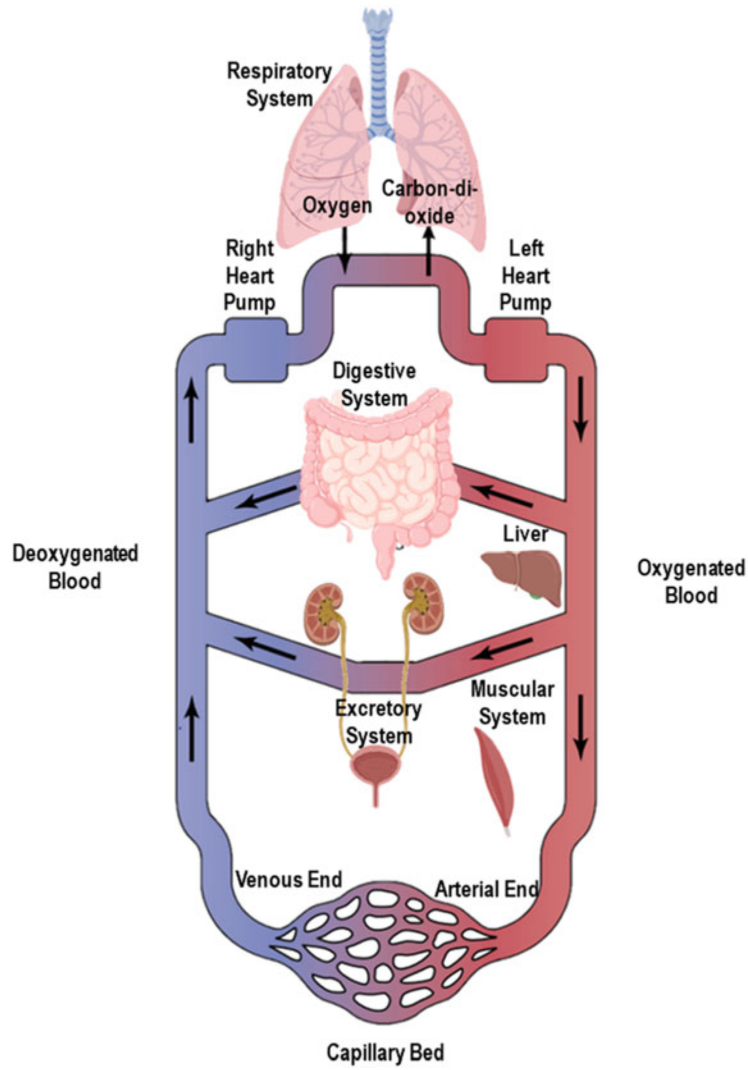


Fig. 1.4 Description of the circulatory system in animals. (Courtesy: BioRender)

> **Know More. . .. . .**
>
> **Blood Groups**
>
> Dogs—8 groups
> Cats—3 groups
> Horse—8 major groups
> Cattle—11 groups
> Goats—5 groups
> Sheep—7 groups
> Humans—4 groups

The icefish does not have either haemoglobin or haemocyanin, which makes it blood colourless. WBCs and platelets account for less than 1% of the blood. WBCs are savage fighters. Pathogenic microorganisms are prevented from entering the animal's body by these organisms. Roughly about 70% of WBCs are phagocytes, which ingest and destroy invading pathogens in a process known as phagocytosis. Lymphocytes produce antibodies. Antibodies bind to the foreign pathogen and prevent it from spreading, whereas platelets form a minute blood fraction. Whenever an animal suffers a cut, they aid in clotting the blood, keeping the wound from becoming infected.

Transporting oxygen to all the cells in the body is the primary job of blood. The role is carried out by RBCs, which contain an essential protein called haemoglobin. So when animals breathe in, oxygen latches onto an active site in the haemoglobin with a single iron atom. We can think of it as a seat on a shuttle bus. The oxygen molecules must first find their seat and put their seat belts on before the bus can move. Once the bus moves, the oxygen molecules are released when they reach their destination, anywhere in the body. The deoxygenated blood hops on while the empty shuttle bus returns to the heart. So the deoxygenated blood has arrived at the heart. Further functioning and structure of heart, arteries, veins, capillaries, and lymphatic system are described in respective chapters.

In recent days, there have been many developments in veterinary cardiology like digital radiography, which helps diagnose congestive heart failures and monitor cardiac and noncardiac causes of cough (e.g. bronchial compression, tracheal collapse, inflammatory airway disease). Various cardiac biomarkers like cardiac troponin 1, N-terminal Pro-B-Type Natriuretic peptides released during contraction and stretch or damage to the heart have been identified. Technological advancements like cell phone heart monitor devices provide high-quality electrocardiograms (ECGs) and animal heart rate data. Moreover, a better understanding of blood transfusion is essential to interpret heart functionality. A technique called xenotransfusion means transfusions between different species. It was practised before the identification of blood groups in humans. No allergy or agglutination events were observed in dogs receiving purified polymerised porcine haemoglobin. Oxyglobin is an ultra-purified polymerised bovine haemoglobin-based oxygen-carrying solution used to treat anaemia in cats and dogs. Using a cell separator system, a cell salvage technique collects blood intra- or post-operation in animals with severe haemorrhage. The blood is filtered and reintroduced to the patients within 6 h as packed red blood cells (pRBC) suspended in saline. Prior to transfusion, anticoagulants and systemic medicines such as plasma-activated clotting factors will be purified.

1.7 Excretory System

The process of removing the metabolic waste and excess water from the body is known as excretion. Each organ, but particularly the excretory system, plays a unique role in maintaining homeostasis. Most of the products reaching the excretory system are metabolised and excreted by the body through sweat, urine, and faeces. The excretory system, also known as the urinary system, consists of kidneys, ureters, bladders, and urethra (Fig. 1.5). In addition to eliminating metabolic waste, the urinary system also regulates the pH of the blood, regulates levels of metabolites and ions such as sodium, potassium, and calcium, and regulates blood pressure and volume. Based on their evolutionary history, surroundings, and feeding and drinking habits, animals produce waste in various ways. These factors regulate water consumption in animals, and most metabolic waste must be

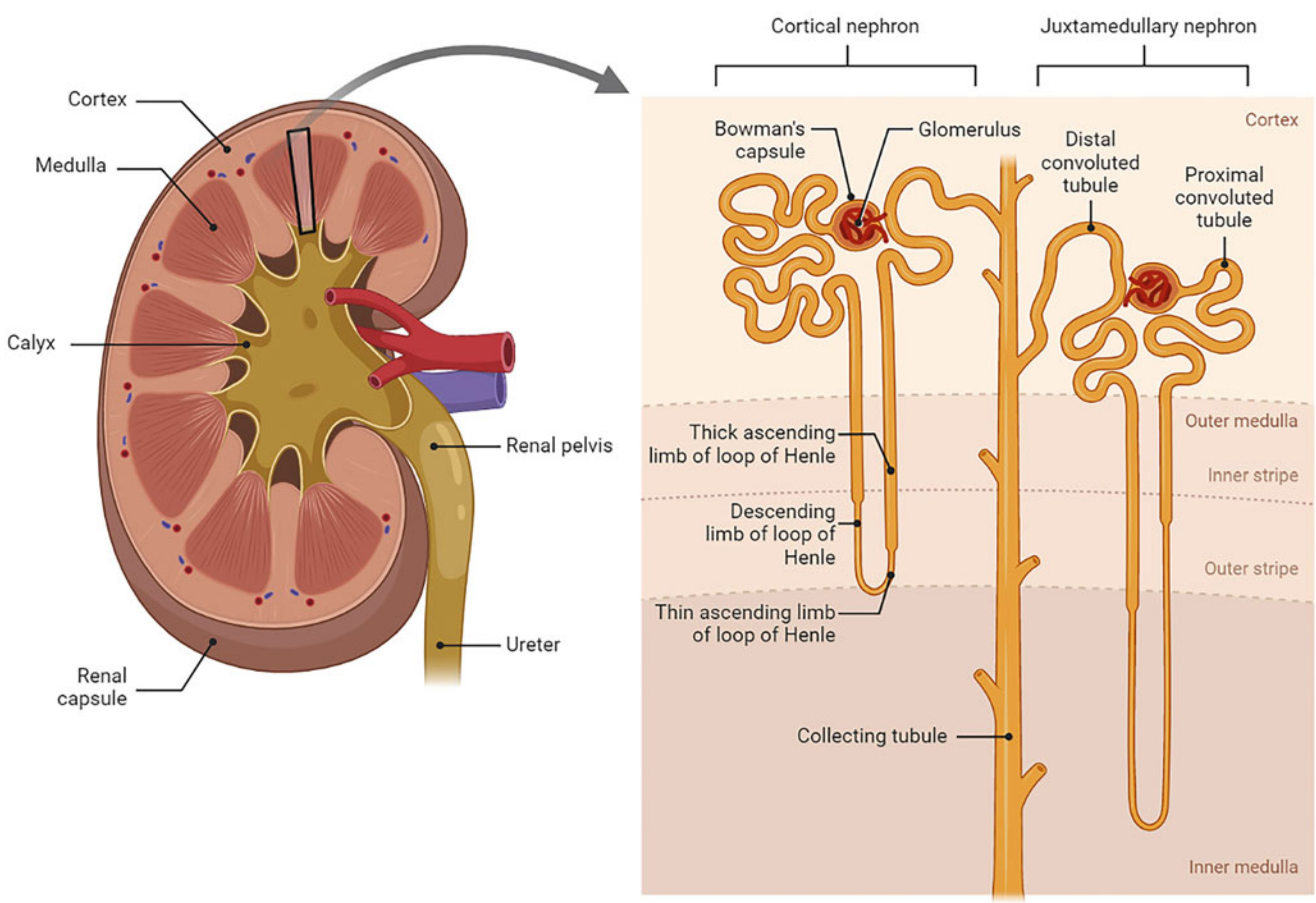


Fig. 1.5 Description of excretory system in animals. (Courtesy: BioRender)

dissolved in water before it can be expelled. The most significant by-product of food metabolism is ammonia, produced by the breakdown of proteins and is highly toxic to the body if stored. Thus, based on the amount of accessible water and the animal's ability to store it, animals transform this ammonia into either urea or uric acid.

Know More. . .. . .

Fun Fact

If one kidney fails to function and is removed, the other kidney can increase in size by 50% within months to handle the entire task of filtration.

The end product of filtration in aquatic animals produces ammonia, expelled directly into the surrounding environment. In comparison, through the process of detoxification, terrestrial mammals convert ammonia-like compounds along with CO_2 into urea in their livers. Birds excrete nitrogenous wastes in the form of uric acid. Even though this process requires more energy, it allows less water to spare, and waste can be excreted as a paste. The kidneys begin by filtering out a large amount of fluid and compounds dissolved in the blood, then reabsorbing around 99% of it before excreting the remaining 1% in the form of urine. Thus, the majority of animals' excretory systems are not exclusively dedicated to excretion but are also well suited for reabsorption. Further detailed description of kidney and its working force are mentioned in the respective chapter.

There are numerous renal disorders in canines; one of the most devastating is chronic kidney disease (CKD). Previously, it was routine treatment with management practices like feeding renal diet, with mediations to prevent load on kidneys. Nevertheless, recently, with the knowledge of stem cells, researchers have bought up with adipose-derived stem cells (ADSCs) therapy. On conducting research, they could conclude that intravenous injection of ADSCs can improve the kidney recovery rate and functional capability in dogs suffering from CKD. In terms of animal welfare, stem cell therapy proved to be adequate to combat CKD.

Another field in nanoscience has the unlimited potential of overthrowing the present medication routines. Nanoscale and novel physiological engineering applications can answer the new dimensions of renal dialysis. Recently, many techniques like permeable selective membrane and nanoscale fabrication process have jumped into the market to treat dogs suffering from renal failure. Various electrokinetic methods for fluid treatment have emerged; for instance, the ion concentration polarisation (ICP) technique which is a part of an electrokinetic purification system acts as an artificial kidney. Through this, a peritoneal dialysis-based wearable artificial kidney device has been a device for end-stage renal disease dogs (ESRD). For dogs exposed to this technique, 10% of toxins were reduced by 3 h. By this, one can expect the wearable artificial kidney to advance more for quality ESRD dogs in the future.

1.8 Digestive System

The animal's digestive system is considered one of the diverse and complex systems. Organs related to the digestive system work continuously as a team to fulfil a single task: transforming the raw materials of the food into essential nutrients (e.g. carbohydrates, fats, proteins, minerals, and vitamins) and energy towards growth, maintenance, and reproduction. Generally, we can divide the digestive system into four main components. (1) Gastrointestinal tract (GIT), which transports food from mouth to rectum; (2) trio organs, i.e. liver, pancreas, and gallbladder, break down the food through enzymes or digestive juices; (3) it is a combination of enzymes, hormones, blood, and nerves, breaks down food, modulates the digestive process, and delivers the final nutrients to respective tissues and cells; (4) mesentery, a membrane that supports and holds the digestive organs to the abdominal wall.

Animals can digest food through various mechanical and chemical processes. For instance, complex food is mashed to pieces mechanically through teeth whenever food enters the mouth, whereas saliva carries out chemical digestion. Enzymes in saliva like amylase convert complex carbohydrates to simpler carbohydrates. To depict an overall pipeline of digestion, food is ingested as mentioned; it is converted into smaller pieces and mixed with digestive enzymes and transported through motor or muscular activities of GIT. In addition to protecting and lubricating the gastrointestinal tract, secretions from the salivary gland, stomach, gall bladder, and intestines also assist digestion. Digestive enzymes hydrolyse the nutrients in the stomach like carbohydrates into simpler sugars, fats into fatty acids and glycerol, and proteins into amino acids. The main job of a digestive system does not stop at the stomach. Abovementioned nutrients need to be absorbed into the bloodstream; this process occurs in the small intestine. Specialised structures called villi in the intestine increase the surface area of the intestines. More the number of villi more the absorption of nutrients. The nutrients are absorbed into the villi through diffusion and transported into the bloodstream through capillaries in the villi. Rest that is not absorbed are pushed out of the system through the rectum. The digestion process in animals varies according to species, habitat, nature of feeding, and many more. For example, ruminants (cattle, sheep, goats) get nutrients through the breakdown of cellulose of plant cells. Here animals depend on large populations of bacteria and protozoa to ferment the food and derive the nutrients to the animal's body. Whereas in simple stomach, animals such as horses and pigs, digestion of food occurs in the stomach with the help of digestive enzymes produced in the stomach. The comparative digestive process has been explained in further chapters.

1.9 Reproductive System

Evolution is the day-to-day process. According to evolutionary biologists, the three major functions of animals are growth, behaviour according to the environment, and reproduction. The biological process by which new individual organisms are produced from their parents is called reproduction. Each organism exists due to reproduction, which is a fundamental characteristic of all forms of life. The offspring represents 50% from the paternal side and 50% from the maternal side. It is because the new-born shares genetic information from both parents. This mixing comes about because of sexual reproduction, which involves the fusion of two sex cells or gametes, called fertilisation. Male and female animals (Fig. 1.6) have different reproductive systems. During puberty, the reproductive organs develop to enable the production of offspring.

The testes produce sperm, the male gametes. In most species, the testes are kept outside the body in the scrotum, except for elephants, rhinoceros, and a few marine animals, like whales and dolphins. The purpose of the external scrotum is to keep the scrotum cooler and is better to form sperm production. The sperm ducts carry sperm from the testes to the urethra, a tube running down the inside of the penis. Spermatozoa are mixed with secretion from glands to produce a liquid called semen. Semen helps carry the sperm into the female reproductive system. The female gametes eggs or ova are released from the ovaries through the process called ovulation. Immediately following ovulation, the egg travels through a tubular passageway called the fallopian tube away from the ovary and towards the uterus. During copulation, the semen is ejaculated from the penis into the female's vagina. These ejaculated spermatozoa swim up through the cervix and uterus. If a sperm manages to reach the ova in the fallopian tube, then fertilisation will occur. After ovulation, the egg only lasts 24 h, whereas the sperm can last up to 3 days (varies according to species). Once fertilisation occurs, the fertilised egg called the zygote will start to divide on reaching the uterus. This cluster of cells will settle into the lining of the endometrium of the uterus. Inside the uterus in a pregnant animal, the fertilised egg cell will continue to divide and differentiate to form different cells. Some will form structures in the embryo and others the placenta. The placenta is an external covering of the foetus where substance exchange between the mother and embryo occurs. Nutrients and oxygen will pass from the mother's blood into the embryos. Embryos receive these nutrients through the umbilical cord. Usually, the embryo is called the foetus after fertilisation at the end of week 8 (varies according to the species). The foetus continues to develop for the entire pregnancy, also called gestation. After the designated gestation period with the combination of different endocrine hormones, parturition occurs. It is the glance at the complete process of copulation to start a new life.

Various reproductive biotechnologies or assisted reproductive technologies (ART) have recently revolutionised livestock productivity to meet the increasing global population food demand. Recent biotechnologies in both males and females, particularly concerning livestock, have revolutionised the reproductive process in vitro and in vivo to improve reproduction and efficiency. Techniques like semen sexing are used to produce offspring of the desired sex. This technique is based on the flow cytometric principle of separating spermatozoa with fluorescently labelled X chromosomes from sperms and fluorescently labelled Y chromosomes. Using this technology, it can sort 15 million spermatozoa per hour into X- and Y-bearing sperms and

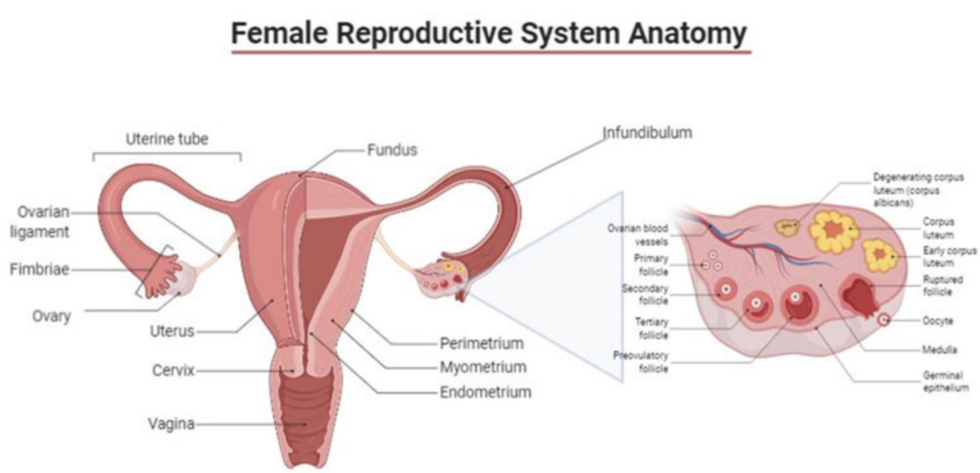


Fig. 1.6 Description of the female reproductive system in animals. (Courtesy: BioRender)

predict the gender of calves with an accuracy of between 85% and 95%. Another technique is named sperm encapsulation, which encapsulates the spermatozoa for longer term preservation in vivo. This technological innovation was intended to allow spermatozoa to stay alive longer in the body's temperature and make the release of viable spermatozoa more progressive over a longer period in domestic animals. Coming to females, Ovum pick-up (OPU) is a non-invasive approach for obtaining large quantities of high-quality oocytes from living animals without invasive procedures. In India, using this technique first buffalo calf named Saubhagya was produced. This method not only improves reproductive efficiency over time but can also be used in follicle ablation to aid in follicle turnover during the embryo transfer protocol.

Additionally, In vitro Maturation, Fertilisation, and Culture (IVMFC) involve the collection of oocytes from ovaries of slaughtered animals trailed by the production of viable embryos through in vitro maturation and fertilisation. The IVMFC approach is ideal for embryo transfer, cloning, transgenesis, and sophisticated in vitro techniques. Intracytoplasmic Sperm Injection (ICSI) is a micromanipulation procedure that involves generating healthy and desirable embryos by mechanically inserting high-quality spermatozoa into the oocyte cytoplasm. ICSI has also been performed on sexed sperm with an 80% success rate in cattle and 48–63% success rate in small ruminants using fresh and frozen-thawed sperm. There are many more techniques like embryo transfer technology (ETT), embryo cryopreservation, embryo sexing, somatic cell nuclear transfer technique, stem cell technologies, transgenesis to counter the demand of increased productivity. Although these techniques have the potential to be effective, they have been hampered by several factors, including the lack of a comprehensive database on indigenous livestock and its biodiversity (which includes traits such as production, reproduction, and disease resistance within species and breeds), which are necessary for their implementation. In the future, the use of these advanced techniques may provide additional insight into the molecular complexities of the reproductive process, including its insanity.

1.10 Lactation Physiology

The process by which mammary glands produce and secrete milk is referred to as lactation. Lactation requires synchronous physiological processes to maintain the homeorhesis of the dam and nutrient acquisition essential for milk formation. It is the most important and expensive phase in dairy animals. The lactation length is about 305 days in cattle, and it varies in different species. Mammary glands are the organs in mammals that produce milk for the sustenance of the young. Mammary glands are among the few structures in mammals that may undergo recurrent growth cycles, functional differentiation, and regression. The mammary gland is derived from the ectoderm during the embryonic stage. Mammary glands include teats, duct systems, lobes, lobules, and secretory tissue. Between puberty and parturition, the formation of ducts and milk-secreting tissue occurs. Mammary gland is modified sweat and exocrine glands, located in the inguinal region in sheep, cattle, goats, horses, and whales; thoracic region in primates and elephants; ventral surface of both thorax and abdomen in pigs, rodents, and carnivores. Delicate membranes separate the front and rear quarters. In cattle, rear quarters produce almost 60% of the milk, while the forequarters produce the remaining 40% and a lactating udder weighs around 15–32 kg. Many factors regulate milk production like age, breed, environment, hormones, and many more.

The process of synthesis and secretion of milk from the mammary alveoli is called lactogenesis. Alveoli are the grape-like clusters containing epithelial cells that absorb nutrients from the blood, transform them into milk, and discharge the milk into the alveolar cavity. Blood supply to the mammary gland is extremely important for its function. Did you know, for every litre of milk produced by a dairy cow, almost 670 L of blood flow through the udder? Further, several hormones play a major role in development of mammary gland and maintenance of milk secretion throughout lactation period. The physiological mechanisms that regulate milk production in cows are multifaceted and extensive. Several cascades and hormonal cycles in the cow's body favour the beginning and termination of milk production. Hence, the lactation stage in the life cycle of a dairy cow is extremely vital considering the production and economic conditions.

Recently, the mammary gland has been considered a bioreactor in a crude way. The mammary gland is like a factory that produces remarkable proteins. So how about genetically engineering the mammary gland after understanding the basic physiology to produce the proteins that are not produced in the mammary gland necessary for consumption. The result of this challenge is transgenesis. Using this technique, we can make the genetically engineered calf harvested for nutraceuticals or bioactive components. This concept is still under research, but the technique offers opportunities to produce milk ideally suited for a particular product, for example, milk specifically produced for cheese. This technique is challenging to harvest from human blood because of its lower concentration. Those proteins can be produced through the mammary gland of animals ranging from rabbits to cows. Anticlotting agents and drugs used to treat angioedema, emphysema, wound healing, and haemophilia have been successfully harvested. Coming to small ruminants, it is now easy to produce monoclonal and polyclonal antibodies that can be used in diagnostic products through genetically modified goats. Most people are lactose intolerant, but no worries; it can be countered by knocking out the α-lactalbumin gene, which drastically reduces the lactose concentration in the milk. Mastitis is the most significant setback in the dairy industry; a study conducted in cows found that a gene encodes lysostaphin in cow's milk to protect against *Staphylococcus aureus* mastitis.

1.11 Environment Physiology

The environment can be defined as the surroundings or conditions in which humans, animals, or plants live or operate. The environment is critical to life on the planet earth. An ecosystem refers to all the living and non-living things that exist in an ecosystem and the ecosystems' relationship to one another. It is the foundation of the biosphere, which governs the overall health of the planet. To make things simple, the environment can be classified into two parts: the biotic environment, which includes all living organisms such as animals, forests, bacteria, fungus, and so on, and the abiotic environment, which includes all non-living components such as temperature, humidity, water vapour, and air. Since industrialisation era human activities from pollution to overpopulation drive up the earth's temperature and fundamentally change the world around us. The leading cause is a phenomenon known as the greenhouse effect. Various gases surrounding the atmosphere, namely water vapour, carbon dioxide (CO_2), methane, nitrous oxide, and chlorofluorocarbons, let the sunlight enter the atmosphere but keep the radiated heat from escaping the earth's surface the glass walls of a greenhouse. The greater the concentration of greenhouse gases in the atmosphere, the greater the amount of trapped heat, strengthening the greenhouse effect and increasing the earth's temperature. Global warming has accelerated as a result of the rapid rise in greenhouse gases in the atmosphere. Climate change has repercussions on the oceans, the weather, food supplies, and human and animal health. Ice sheets such as Greenland and Antarctica are melting. Sea levels rise due to the excess water once contained in glaciers spilling out into the oceans, swamping coastal regions. Furthermore, more intense storms, flooding, heavy snowfall, and droughts incidents are getting more common. These fluctuations in the weather present difficulties; cultivating crops becomes more challenging.

As mentioned, environment plays a significant role in the productivity of an animal. In this changing environment, the animal gets exposed to different stressors, like heat stress, nutrition stress, walking stress, water stress, transportation stress, and many more. Animals have evolved mechanisms to manage short-term stressors. During the short-term exposure, the biological cost is minimal because adequate reserves of biological reserves exist to cope with the stressor and meet the impact of the stress without any disturbances on biological functions. If the animal gets challenged by multiple stressors, there will be insufficient biological reserves to satisfy the biological cost of the stress response; to counteract this, resources will be channelled from other biological functions. As shown in Fig. 1.7, when resources are sidetracked from productive functions, it leads to impairment of biological functions. For example, when multiple stresses deplete body reserves, metabolism shifts away from growth, the young animal no longer blooms, and growth is restricted. When energy is shifted from reproduction and its process, reproductive success is reduced. This metabolic maintenance behaviour of an animal's body rather than production will last until the animal restocks its resources/reserves sufficiently to re-establish normal functions.

Livestock acts as a significant contributor to global food security, particularly in fringe lands where livestock is characterised as a protein, energy, and micronutrient source. Global climate change has a considerable effect on the livestock sector, depending on different ecosystems and natural resources. Looking at the different climate change predictions, we can envision the future of the great struggle to adjust and adapt to new environmental challenges both by humans and livestock. To ensure food security, policymakers and researchers should prioritise identifying animals with superior genetic traits that are economically beneficial and identifying biomarkers for a solution to animal productivity loss due to climate change, especially when animals are exposed to multiple stressors.

As mentioned previously, homeostasis is a mechanism that maintains physiological stability through interaction between internal processes and the external environment. One of the routes to achieve is through thermoregulation.

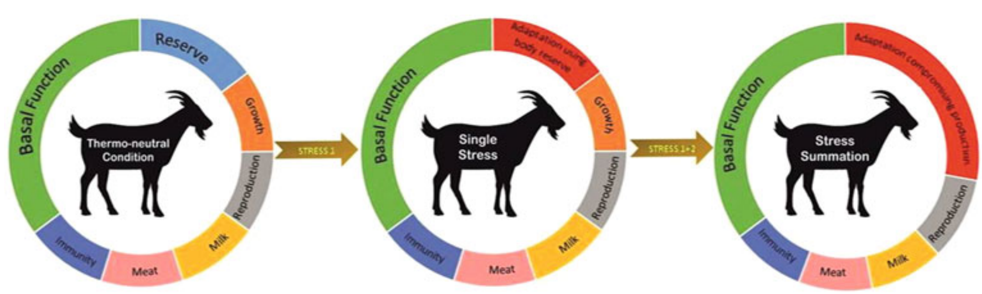


Fig. 1.7 Pictorial representation of summation effect of multiple stresses in goats. (Source: Sejian et al. 2018)

Thermo conformers and thermo regulators are the two types of organisms. The internal temperature of thermo conformers depends on the external environment, whereas thermo regulators maintain their internal body temperature within a particular limit, still being responsive to external stimuli. There are a variety of reasons that contribute to the distinction in temperature regulation among organisms. These include adaptation, mutation, and environmental stimulation. There are different adaptation strategies developed during their lifetime to maintain the desired body temperature.

On exposure to heat stress few animals loose heat through sweating (e.g. horses, humans). Rats, mice, dogs, and cats all have sweat glands on the soles of their feet. Rather than that, many mammals (e.g. dogs) pant to cool themselves. Vasodilation is another method of releasing heat from the body. Those blood vessels closest to the skin's surface expand wide and allow blood to flow through them. Blood gets cooled down as the heat radiates out of the body. In contrast to heat loss, animals employ the opposite mechanisms to retain heat when the ambient temperature falls below the core body temperature. Vasoconstriction is accomplished by subdermal capillaries, which redirect blood away from the skin and body's periphery. In extreme cold, prolonged blood rerouting away from the extremities results in numbness and cellular damage (e.g. frostbite). Animals contract minute subdermal muscles (erector pili) to erect dermal hair follicles to increase heat retention. These erect hairs form a heat-trapping insulating layer.

1.12 Omics in the Field of Physiology

Omics is a science branch that aims to characterise and quantify many biological molecules that decode into an organism's structure, function, and dynamics. Before understanding the purpose of Omics and different Omics technologies and their functional capability in physiology, let us look at the mega human genome project, the starting point for Omics. The Human Genome Project was a massive undertaking involving scientists worldwide working together to decipher the deoxyribonucleic acid (DNA) sequences that make up the human genome. The project began in 1990 and was finished in 2003, 2 years ahead of schedule. Researchers decrypted the mystery of DNA. According to them, the genome of every person on earth is 99.9% the same. It is that tiny 0.01% that makes up genes that give us our unique differences. An essential aspect of the human genome project is to identify any mutation in a gene order that could lead to disease. Scientists can use this information to extrapolate the genetic causes of diseases and develop treatments for the variants of genes or alleles associated with various inherited disorders. Genetic tests can be performed on individuals to determine whether they are carriers or sufferers of an inherited disorder. It took 13 years and billions of dollars to sequence the whole genome during the human genome project, but now researchers can do it in a few hours and for a relatively low charge.

Animal researchers have the same goals of identifying gene variants that add to good health and further increase the food production capacity and quantity of animal products. Much of the match for functional gene annotation for animal sequences comes from human orthologues. Even though advances are made in physiology and allied sciences; however, full potential has been not achieved in Omics work, for instance, Sire-based evolution using genomics for future productive offspring production.

Through a wide range of Omics techniques, it is possible to get insight into an animal's sensory system and surroundings. For instance, pufferfish, when exposed to cold stress, more than 5000 differentially expressed genes (DEG) popped up. Further, only a few differences were in proteins and metabolites. This study reflects the importance of different Omics approaches. If only transcriptomic data were be considered, it might not have reflected proteins and metabolites at a single stretch. However, when proteomics and metabolomics were combined, it gave the network analysis. It revealed that different molecular interactions were associated with immunity, metabolism of fatty acids, transport of bile salts, and lipolysis, suggesting that these processes were essential for pufferfish to withstand cold stress. This study can be the best example to weigh the multi-Omics approaches in the field of physiology.

We search for robust breeds in different species to fulfil the global food demand in this present climate change. Heat stress and nutrition stress are the major abiotic stressors for dairy cattle. Although Omics science has advanced, heat stress's direct and indirect impacts remain key obstacles in understanding the interaction between genetic polymorphism, genes, transcripts, proteins, and metabolic pathways connected to productive qualities like milk and meat output. To give a better perspective, let us imagine cattle is subjected to multiple stressors (thermal, nutritional, and walking stress). In response to the stress, the homeostatic mechanism triggers to counteract those stressors in cattle. It can be quantified using genomics, which identifies the genes, SNPs associated with stress resilience via genome-wide association studies (GWAS).

Further, epigenome studies propel us to the identification of DNA modifications that change accessibility for transcription. A transcriptomic study allows the quantification of the mRNA (gene transcripts) in different tissues in response to stress response (Fig. 1.8). It can be cross verified through proteome, examining the entire set of proteins after translation from mRNA and post-transcriptional modifications. Additionally, metabolomics gives us an idea about lipids, water-soluble and volatile molecules formed after protein

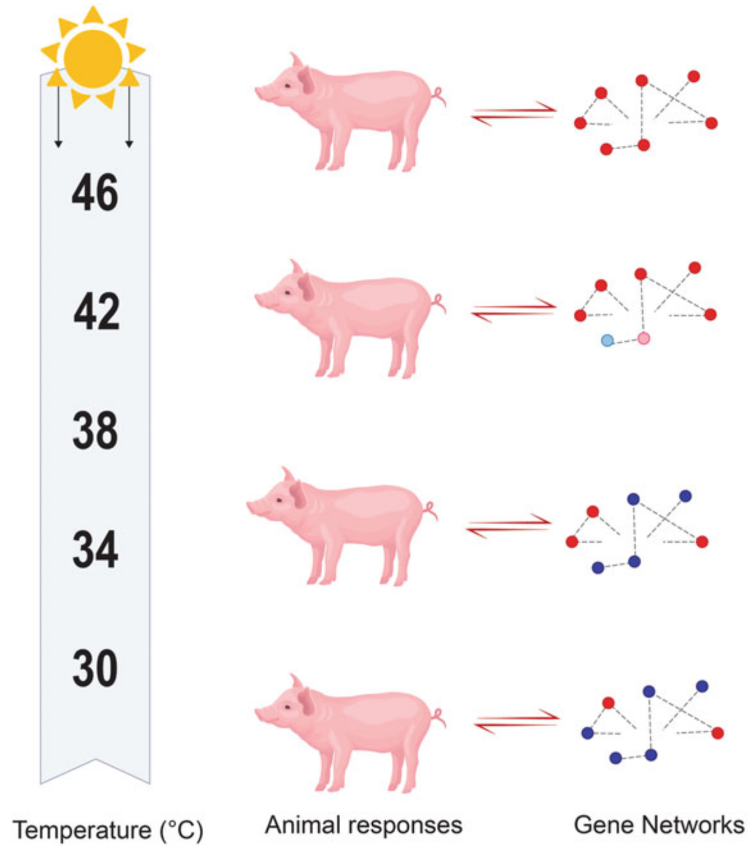


Fig. 1.8 Pig is exposed to an increase in temperature and each level transcriptomic response is recorded. Transcriptomic changes are made to improve the individual's response to heat stress. As the temperature increases, transcriptomic adjustments are made such that animal gets acclimatised to the changing environment through changes in their physiological modifications by animals. (Courtesy: BioRender)

and enzyme activity occur or formed because of these reactions.

Another area of interest for many researchers is the complex relationship between ruminants and rumen-dwelling microbiota. Based on sequencing target regions of the 16S rRNA gene, the characterisation of rumen microbiota can be done. It enables us to characterise the microorganisms and their functional contributions to the host's energy production. Nevertheless, this process will not fetch information about their functionality. However, multi-Omics science such as metagenomics, transcriptomics, metaproteomics, and metabolomics provides deeper comprehension of the ecology of rumen microbiomes, the symbiotic host–microbe relationship, and the impact of different nutritional factors manipulations on the productivity of animals. Metagenomics enables the assessment of the microbiome's diversity and potential functional capacity, whereas metatranscriptomics can shed light on the microbiome's actual function via gene expression. Metaproteomics and metabolomics, when used together with metatranscriptomics, can aid in identifying the members of an active microbial community. Additionally, they give information on differentially expressed metabolic pathways by utilising NMR or MS-based approaches to access the proteins expressed and metabolites generated. While next-generation sequencing and functional metagenomics are being used to study the rumen microbiome in tropical animals, integrating the results with other meta-Omics remains a challenge.

Learning Outcomes

- With the basic understanding of a complex yet unique bunch of living units—cells combined with recent developments, one can anticipate the future with agricultural and biomedical applications such as the production of genetically engineered animals.
- A better comprehension of the integration system includes the nervous and endocrine systems, which are primarily responsible for maintaining the animal's metabolic homeostasis. Signals from neurons are precisely targeted, but signals produced from the endocrine gland are broad-spectrum signals distributed throughout the animal's body. Coordination of both chemical and electrical systems is critical for maintaining balance within the animal.
- Exchange and transport systems, i.e. respiratory system and circulatory system, work together to supply cells and tissues with the necessary oxygen and metabolites so that they can operate optimally.

(continued)

- Kidneys act as a regulator of plasma with various functions like regulating pH, osmoregulation, and filtration of nitrogenous waste and metabolic waste products as a means of achieving homeostasis either naturally or through technological advancements.
- Deeper insights into various reproductive structures present in different types of animals, the role of hormones in gametogenesis, ovulation, and implantation and most importantly, various assisted reproductive technologies to meet global food demand.
- To appreciate the physiological mechanisms controlling the growth and development of the mammary gland—factors influencing milk secretion. To acknowledge recent developments in the field of the genetically engineered mammary gland.
- Influence of environment on various metabolic activities in animals. Causes of climate change and its impact on animal adaptation and effect of multiple stressors on animal productivity. General mechanism of thermoregulation in adapted animals.
- Basics and history of the human genome project. The advantage of multi-Omics research to increase animal productivity in this present climate change situation.

Exercises

Objective Questions

Q1. The average size of cells is ___________________.

Q2. The animal nervous system is capable of a wide range of functions. The basic unit of the nervous system is ___________________.

Q3. How do neurons communicate with one another?

Q4. Which is the primary glucocorticoid produced in the ruminants?

Q5. Thyroxin is responsible for ___________________.

Q6. Cells absorbs oxygen through ___________________.

Q7. Pigment responsible for blue blood colour in octopus is ___________________.

Q8. Major excretory product in birds is ___________________.

Q9. Give some examples of assisted reproductive technology.

Q10. Mammary gland is derived from the ___________________ layer during embryonic stage.

Q11. Profuse sweating animal other than human is ___________________.

Q12. Human genome project started in the year ___________________.

Answer to Objective Questions

A1. 0.01–0.1 mm

A2. Neurons

A3. Electrically and chemically

A4. Cortisol

A5. Promoting the growth of tissues in the body

A6. Diffusion

A7. Haemocyanin

A8. Uric acid

A9. Sperm sexing, embryo transfer, and artificial insemination

A10. Ectoderm

A11. Horse

A12. 1990

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Further Reading

Research Articles

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