National Universities Commission

Core Curriculum and Minimum Academic Standards (CCMAS)

CCMAS Book Series

Fundamentals of Veterinary Medicine

Book 1

Editors

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Core Curriculum and Minimum Academic Standards (CCMAS)

Veterinary Medicine

Fundamentals of Veterinary Medicine
Book 1

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Foreword

The National Universities Commission is empowered by the Education (National Minimum Standards and Establishment of Institutions) Act, CAP E3, Laws of the Federation of Nigeria, 2004, to lay down minimum academic standards in Nigerian Universities and to accredit the degrees therefrom. According to this and in its sustained commitment to the revitalisation of the Nigerian University System, the Commission launched the "Core Curriculum and Minimum Academic Standards (CCMAS)", in December 2022. The document has been adjudged by both internationally and locally revered scholars, as a standard and fit-for- purpose, designed to meet the demands of the 21st Century.

To ensure the efficient delivery of the CCMAS, it has become fitting and necessary to develop a reference document that would contain innovative and simple topics for all disciplines/programmes to serve as a guide for students and lecturers. This novel idea informs the development of the CCMAS Book Series, which presents to Nigerian universities the fundamentals of each discipline, aimed at deepening the understanding of the CCMAS, for the overall improvement in teaching and learning, and ultimately, for the production of nationally relevant and globally competitive graduates from the System.

The excitement and wide acceptance of the Book Series stems from the fact that several scholars in their respective disciplines sent in their contributions, which are rated topnotch in all ramifications. There is no gainsaying that the Book Series is a welcome masterpiece as it expounds what the CCMAS offers and the many lessons and motivations to draw from its optimal implementation, for the overall good of society.

The effort of the National Universities Commission in the development of the CCMAS and following up with associated innovative initiatives like the CCMAS book series is commendable. Consequently, I congratulate the Executive Secretary, National Universities Commission, Professor Abubakar Adamu Rasheed *mni, MFR, FNAL* for adding another feather to his feather-filled cap within his reltively short period in NUC. Kudos must be given to the Distinguished Emeritus Professor Okebukola led NUC Strategy and Advisory Committee (STRADVCOM) and staff of the National Universities Commission

for driving this process to fruition. There is no way this initiative can become a reality without the contributions of the scholars who developed the texual materials. Consequently, I laud the erudite scholars of Nigerian universities, who have demonstrated their love for academic excellence in sharing their knowledge with humanity through the instrumentality of this project.

I commend the CCMAS Book Series to staff and students of Nigerian universities and indeed to scholars all over the globe as the contribution of the Nigerian University System to academic development and excellence.

Happy reading.

Malam Adamu Adamu
Honourable Minister of Education

Preface

In keeping with its mandate of making university education in Nigeria more responsive to the needs of the society, the National Universities Commission commenced the journey to restructure the BMAS in 2018, introducing in its place, the Core Curriculum and Minimum Academic Standards (CCMAS), to reflect the 21st Century realities, in the existing and new disciplines and programmes in the Nigerian University System. The arduous process, which was birthed through continued stakeholder interactions over the course of four years, produced seventeen documents to cater for each of the disciplines in the Nigerian University System. A key feature of the CCMAS document is the unique structure that provides for 70% of core courses for each programme, while allowing universities to utilise the remaining 30% for other innovative courses in their peculiar areas of focus.

Following the conclusion of the development and review process as well as a series of editing, the CCMAS documents were launched in a grand ceremony on the 5th of December 2022. With the launch, the job of the Commission was far from over as this was only the beginning of a three-phase process in the development/review and implementation of the CCMAS document. Having completed phase one, which is the launching of the CCMAS, NUC proceeded to phase two, which involves the development of the 30% CCMAS by the universities. At the same time, the plan for capacity building for effective implementation of the CCMAS as well as the development of textual materials to support the implementation of the CCMAS were taken on board.

The need to have customised (bespoke) texts to support the implementation of the CCMAS was pointed out by an erudite Professor (President of the Nigerian academy of Education) during one of the General Assemblies and was processed through the NUC Strategy and Advisory Committee (STRADVCOM). Emeritus Professor Nimi Briggs was unanimously nominated as the Project Coordinator. The series of textual materials are called the *CCMAS Book Series* and titled *Fundamentals Series* in the first project.

The contributors across the 17 disciplines have been drawn from the six geopolitical zones and proprietorship of universities such that there is collective ownership. The major denominator for selection was scholarship in the discipline, which was reflected in the narrative of each book. The various

chapters showcase and give examples from local published research so that visibility can be given to ideas from Nigeria and Africa on the topics. While definitions and models from "western" scholars are mentioned, these are de-emphasised as much as possible. The time is ripe to show the world, through this book, that Nigerian scholars, over the last 70 years at least, have been in the frontline of research in the published topics and now able to provide generic and contextual definitions, models and examples in the respective disciplines for scholarly work the world over.

The contents target the compulsory courses in the CCMAS and will be published in a series. As much as possible, the books attempt to sync with the levels of delivery of the curriculum that is 100 level; 200 level and so on. The books are written in very simple English, well-illustrated and rendered in the typical course-material format of objectives, content to be learned, summary, evaluation, exercises and references.

The Commission is optimistic that these series will serve as a guide to support the implementation of the CCMAS documents in the Nigerian University System and beyond and adequately equip the trainers and students in making university education more responsive to the needs of society.

Professor Abubakar Adamu Rasheed, *mni, MFR, FNAL, HLR*
Executive Secretary

Message from the Project Coordinator

Emeritus Professor Nimi Briggs (RIP)

With the launching of the 17 documents of the new Core Curriculum and Minimum Academic Standards (CCMAS) on Monday 5th December 2022 by Vice- President Professor Yemi Osinbajo, *GCON,* Nigeria's National Universities Commission (NUC) accomplished a major feat in its quest to rapidly revitalise the nation's university system.[1] In this regard, the Commission working though its *Strategy Advisory Committee (STRADVCOM),* had, in 2019, identified 10 priority areas that needed urgent attention, one of which is, the introduction of a reengineered curriculum that addresses 21st century challenges. Such a curriculum, it was envisaged, should lay emphasis on skills acquisition and learning outcomes and should be able to stand side by side with those from the World's best universities in the quality of its content as well as being relevant on issues affecting the local communities in which individual universities are located. Thus, CCMAS documents were developed to provide 70% of the contextual materials and compulsory credit units required for graduation at the bachelor's level across the entire chain of degree courses offered by all universities in the country.

That done, attention shifted towards enabling individual universities to develop the additional 30% of the curriculum from issues that are peculiar and relevant to their core mission and local circumstances, as approved by Senates of their individual universities, capacity building and training of staff on the delivery of the CCMAS and the production of books that would cover the contextual materials of the CCMAS.

It is expected that utilisation of the CCMAS series in the Nigerian Universities System will commence in the 2023/2024 academic session. Stringent efforts were therefore made to conclude the production of the series of books, the first in the series, well in advance of that period.

Nimi D. Briggs
February 2023

Note: Sadly, Emeritus Professor Nimi Briggs passed on April 10, 2023. He is resting in the realisation that this project is "safely delivered", he being a globally renowned scholar in obstetrics and gynecology.

Editors' Note

It is our pleasure to serve as editors of the first in the series of books on the Core Curriculum and Minimum Academic Standards (CCMAS) for the Veterinary Medicine Discipline. Book 1 of the ***Fundamentals of Veterinary Medicine*** covers the contents of the compulsory courses for 100 level and 200 level students. The book has benefited from multiple authorship from senior academic staff, mostly Professors, who have taught the topics in their respective chapters for at least five years. Contributors are drawn from Faculties/Colleges of Veterinary Medicine in Nigerian universities from all the six geopolitical zones in the country. This is to give room for the amalgamation of home-grown expertise from across the country on the different topics to the benefit of the students.

The development of the book was in stages i.e., setting up of Editorial Committee and layout of chapters; call for expression of interest to contribute to the book; selection of contributors; development of first draft; plagiarism check; collation of first draft by Editorial Team; three-way review by members of Editorial Team, expert Professor/Associate Professors in respective fields and 300 level students across universities in Nigeria; revision of Version 1 based on reviewers' feedback and production of Version 1.1.

We encourage all Veterinary Medical students in the Nigerian University System to take full advantage of the wealth of information presented in the book as a veritable resource material. Also, the book is recommended to teachers in Faculties/ Colleges of Veterinary Medicine in Nigeria as a guide in the delivery of the CCMAS.

Yusuf O. Aliu
Omolade Oladele

Editors

Courses covered in Fundamentals of Veterinary Medicine Book 1

VAN 201: Gross Veterinary Anatomy I
(3 Units C: LH 30; PH 45)

Learning Outcomes
At the completion of this course, students should be able to:
1. explain the nomenclature of structures of the organ system;
2. describe relative positions of organs in the body and the relationships with one another; and
3. correlate the knowledge acquired to radiology and surgery courses at the clinical levels.

Course Contents
Definition of anatomic terms. The basic gross anatomy of the animal body, skeletal system, respiratory, digestive, circulatory and lymphatic systems of a type animal. Comparative anatomy of internal organs. General plan of circulation, heart, arterial and venous systems. Pulmonary and systemic circulation. Respiratory system; pleural cavity (visceral and parietal pleura). Larynx and tracheal anatomy, differences in sheep and goat. Digestive system (ruminant). Lymphatic system; major lymph nodes in thorax and abdomen. General osteology, myology, arthrology.

VAN 202: Gross Veterinary Anatomy II
(3 Units C: LH 30; PH 45)

Learning Outcomes
At the completion of this course, students should be able to:
1. explain the nomenclature of structures of the organ system;
2. describe relative positions of bones and organs in the body; and
3. demonstrate competence in dissection to see, *in situ,* the organs of the body and their relationships with one another.

Course Contents
Urogenital System (Ruminant): Kidney (Large and Small Ruminants), ureter, bladder, and urethra. Male urogenital peculiarities (urethra to glans penis), urogenital folds, spermatic cord, testes and epididymis, inguinal canal, accessory sex organs. Female urogenital system, urethra to vulva, ovaries to vagina. Broad ligament. Recap blood and nerve supply to reproductive system. Neuroanatomy and structures in the head (Ruminant): superficial structures of the head, horn, canthus, commissures, nasal anatomy. Bones of the skull, special joints of the skull. Muscles of the head. Major blood and nerve supply to the head. Structures of the brain. Circle of Willis.

VAN 203: Histology
(3 Units C: LH 30; PH 45)

Learning Outcomes
At the completion of this course, students should be able to:
1. identify each organ microscopically;
2. demonstrate the practical skill to use the microscope; and
3. identify histological uniqueness of some organs across species.

Course Contents
History and introduction to microscopy and microscopic techniques: History and introduction to the cell, membrane structure, and cell surface modification, nucleus, principle of protein synthesis, exocytosis and endocytosis, gap junction and cytoskeleton. Organelles: mitochondria, ribosomes, endoplasmic reticulum, Golgi apparatus, lysosomes. Epithelia tissue: different types, examples of where they are found, glandular epithelium (exocrine and endocrine). Connective tissue: Cells, fibres, ground substance. Muscular tissue: Skeletal, smooth, cardiac, basic ultrastructure of muscle unit. Nervous tissue: Basic neuron, neuron types, ultrastructure of neuron, myelin, synapse, glial cells, peripheral nerve ganglion, choroid plexus, sensory receptors, blood brain barrier. Systemic Histology: Microscopic study of the organ systems of the body of animals. Comparative Histology of the organ systems of animals.

VBC 201: Biochemistry I (Chemistry and Biochemistry of Carbohydrate and Protein. Abnormalities of Carbohydrate and Protein Metabolism) (3 Units C: LH 30; PH 45)

Learning Outcomes

At the completion of this course, students should be able to:

1. explain the chemistry and biochemistry of carbohydrates and proteins;
2. describe the abnormalities of carbohydrates, protein, amino acids; and
3. explain haemoglobin metabolism.

Course Contents

Pathways of metabolism of glucose and fructose, and control of carbohydrate metabolism. The electron transport chain (ETC) and oxidative phosphorylation. Chemistry and structure of amino acids, peptides and peptic bonds, and metabolism of amino acids and amino sugars. Essential and non-essential amino acids. Classification, structure and functions of proteins. Urea cycle and its biochemical importance. Glucose-6-phosphate dehydrogenase (G6PD) deficiency. Inborn errors of metabolism of some amino acids e.g. (phenylketonuria, tyrosinosis, alkaptonuria, albinism, cystinuria). Structure, properties, and biochemical functions of Haemoglobin, Porphyrins and Porphynurias. Functions of bile pigments; jaundice. Haemoglobinopathies, HBS, thalassemias, heamophilia, etc.

VBC 202: Biochemistry II (Chemistry and Biochemistry of Lipids. Nutritional Biochemistry. Fluid and Electrolyte Balance) (3 Units C: LH 30; PH 45)

Learning Outcomes

At the completion of this course, students should be able to:

1. explain the chemistry and biochemistry of lipids, nutritional biochemistry, fluid and electrolyte balance; and
2. describe major nutritional, vitamins, fluid and electrolyte deficiencies.

Course Contents

Introduction, classification, chemistry, and functions of lipids. Digestion and absorption of lipids, formation of chylomicrons, transport of lipids in blood

stream, lipoproteins. Biosynthesis of fatty acids, the triacylglycerols, phospholipids, sphingolipids and regulatory mechanism involved. Metabolism of cholesterol, biosynthesis and deregulation into bile acids and bile salts, etc. Biochemistry of prostaglandins and nutritional biochemistry: General nutritional requirements. Energy aspects of diets, basal metabolic rates (BMR), and specific dynamic action. Major nutritional disorders e.g. obesity, marasmus, kwashiorkor, and marasmic-kwashiokor. The water-soluble vitamins, vitamin C and their biochemical importance in the body. The fat-soluble vitamins: A, D, E and K and their biochemical functions. Calcium and phosphorus metabolism and significance in the body. Trace elements: Mg^{2+}, Mn^{2+}, Zn^{2+}, P, Co, Li^{2+}, etc.

Fluid and electrolyte balance: Fluid intake and output, total body water distribution in intracellular and extracellular fluids. Functions of electrolytes, dehydration, and its correction. Water and the major ions: HCO_3^-, Cl^-, Na^+, K^+, H^+ Regulations of water balance. Iron: sources, absorption, distribution in the body and biochemical functions and excretion. Anaemia, heamochromatosis. Chemistry and biochemistry of carotenoid. Biochemistry of Vision. Coenzyme, structure, and roles in cellular metabolism.

VBC 204: Introductory Molecular Biology
(2 Units; C: LH 15; PH 45)

Learning Outcomes

At the completion of this course, students should be able to:

1. describe the principles and explain the interrelationships between structure, functions and molecular mechanisms that underlie the functions of a normal cell; and
2. acquire basic techniques in cell and molecular biology.

Course Contents

Sub-cellular and molecular basis of cell function and mode by which cells multiply, replicate and pass genetic information including DNA structure and protein synthesis. Methods of gene splicing and genetic engineering. Chemistry and structures of nucleic acids. Nomenclature of bases, nucleotides

and nucleotide biosynthesis. Composition of DNA and RNA. The Watson-Crick DNA double helix. Genetic regulation of metabolism. Introduction to genetic engineering in veterinary medicine. Virus and oncogenes. Programmed cell death, Biochemistry of free radicals.

VPY 201: Veterinary Physiology I (Blood, Circulatory and Respiratory Systems)
(3 Units C: LH 30; PH 45)

Learning Outcomes
At the completion of this course, students should be able to:
1. describe morphology, function and disorders of blood cells;
2. describe oxygen supply to tissues and exchange of gasses in tissues; and
3. explain control of breathing and mechanisms of body temperature regulation.

Course Contents
Structure and functions of blood, production, degradation of blood cells. Anaemia, blood coagulation, plasma proteins and blood volume measurement. Cardiovascular physiology: structure and functions of the heart; the dynamics of blood and lymph flow. Blood pressure and heart rate control and regulation. Circulation of blood through special organs e.g., lungs, heart, brain, liver, and kidneys. Respiratory Physiology involves the function of the respiratory system and properties of gas. Mechanism of respiration and gas exchange in the lungs Regulation of respiratory and buffers in the blood.

VPY 202: Veterinary Physiology II (Endocrinology, Renal and Digestive Systems)
(3 Units C: LH 30; PH 45)

Learning Outcomes
At the completion of this course, students should be able to:
1. determine the location of different endocrine glands;
2. describe the functions of endocrine factors;
3. explain the interrelationship between endocrine and nervous system;

4. explain the involvement of endocrine system in animal production and glomerular filtration;
5. describe the functions of the kidneys, glomerular filtration, water excretion, acidification of urine and bicarbonate excretion; and
6. explain electrolyte (e.g., potassium and sodium) excretion.

Course Contents
Introduction to endocrine system as a control system in the body; endocrine organs and their secretions. Characteristics and mode of action of hormones. Mechanism of secretion, regulation and function of hormones from the pituitary, thyroid, parathyroid, adrenal, pancreas and thymus glands. Effects of hypo- and hyper-secretions of the above-named glands in various animals. Physiological control systems and feedback mechanisms. The role of the kidney in homeostasis. Nephron - the functional unit of the kidney. Glomerular filtration and tubular functions. Water and electrolyte excretion and absorption. Digestion in monogastric animals, prehension, mastication and swallowing. Saliva production and function. Gastric juice production, digestion, and absorption of food items. Digestion in the ruminant stomach and intestinal motility. Hormones of the gut Avian digestion.

VPY 204: Veterinary Physiology III (Central and Autonomic nervous systems, Special senses and Muscles)
(3 Units C: LH 30; PH 45)

Learning Outcomes
At the completion of this course, students should be able to:
1. describe the role of the nervous system in maintaining homeostasis;
2. explain nerve cell communication;
3. outline the structures and divisions of the nervous system including their roles;
4. describe how the brain and the spinal cord are protected and nourished;
5. distinguish between the parasympathetic and sympathetic division of the autonomic nervous system;
6. identify the special senses, their structure and function; and
7. relate types of sensory receptors to their function and the nervous pathways to the central nervous system.

Course Contents
Impulse propagation and conduction. Central and autonomic nervous systems. Reflex mechanisms and types. Neurotransmitters, motor functions of the spinal cord, ascending and descending fibre tracts of the spinal cord. The brain, hypothalamus, and limbic systems. Sleep and wakefulness. Physiological properties and functions of the autonomic nervous system, muscles and bones. Physiology of special senses, olfaction, gustation, hearing and vision.

VHM 201: Food Animal Production and Management (2 Units C: LH 15; PH 45)

Learning Outcomes
At the completion of this course, students should be able to:
1. identify livestock species (cattle, sheep and goats) by breed;
2. handle food animals; and
3. explain production systems and health management practices on farms.

Course Contents
Introduction to livestock husbandry. Livestock species, breeds and distribution. Animal behaviour. Livestock production systems: extensive, semi-intensive, intensive. Estimation of live-weight and age. Emphasis on birth weight, litter size, weaning age/weight, growth rate. Disbudding, dry hoof trimming. Tagging and branding. Restraint techniques and handling. Animal transportation. Nomadism, pasture management, animal housing.

VHM 202: Companion and Wild Animal Management (2 Units C: LH 15; PH 45)

Learning Outcomes
At the completion of this course, students should be able to:
1. demonstrate the handling of companion animals such as dogs, cats, horses, etc and analyse their behaviour; and
2. demonstrate how to handle and provide care for wild animals in captivity.

Course Contents:
Housing and grooming of companion animals. Types/breeds of dogs and cats. Uses of dogs. Bathing tips, tooth care. Basic training of puppies and adult dogs. Husbandry of camels, horses, buffaloes, donkeys and their uses. Restraint techniques and animal handling. Feeds and feeding of companion animals. Kennel and stable management. Application of modern techniques in routine management and health of companion and wild animals. Animal transportation. Care of the hoof.

VHM 203: Poultry and Fish Production and Management
(2 Units C: LH 15; PH 45)

Learning Outcomes
At the completion of this course, students should be able to:
1. identify the types and breeds of poultry and fish; and
2. explain housing, feeding and other health management practices necessary for poultry and fish production.

Course Contents
History of the domestic fowl. Types and breeds of poultry. Special husbandry (housing and feeding) requirements of broilers, layers, breeders and cockerels. Special husbandry requirements of turkey, guinea fowl, duck, ostrich and quail. Hatchery management. Inspection and care of day-old chicks. Biosecurity measures on poultry farms. Conditions that affect the health of fish stock. Aquaculture biosecurity protocols. Strategies to manage and maintain the health and well-being of fish in aquaculture facilities. Monitoring fish health. Health consideration in fishpond management.

VHM 204: Animal Welfare
(2 Units C: LH 30)

Learning Outcomes
At the completion of this course, students should be able to:
1. state the legal and regulatory framework for animal welfare and animal euthanasia;

2. demonstrate social responsibility for animal well-being and reducing animal suffering;
3. determine the effective measures to apply when adverse events occur in animals; and
4. select the best practices for animal use in research.

Course Contents

Definition of the term 'Animal Welfare'. Legal and regulatory framework for animal welfare including right to kill. Animal population dynamics in relation to animal welfare. Humane transportation, killing, disposal and harvesting. Care of animals during disaster. Animal freedom and behaviour (freedom from pain, injury and disease, fear, stress and discomfort and freedom to express normal behaviour). Animal care in research (International standards and best practices in research and training). Provisions in the criminal and penal codes on animal mishandling and welfare.

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Contents

Chapter 1

VAN 201: Gross Veterinary Anatomy I

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Overview

Veterinary Gross Anatomy is the study of animal body structures at tissues, organs, systems and organismal levels using different anatomical techniques. The course Veterinary Gross Anatomy is the foundation of Veterinary Medicine. It is important because a sound knowledge of animal anatomy, their organs and topographical relationships is required in all areas of veterinary practice such as Meat hygiene and Inspection, Anatomic Pathology, Surgery, Obstetrics and Theriogenology and Veterinary Diagnosis. The methods used in teaching Veterinary Gross Anatomy, include delivering of lectures and dissection practical classes. The lectures are delivered on organ – system basis while the dissection is carried out using the regional approach. The *comparative anatomical features* in different species will are addressed in the various systems of this course and students should be able to know and identify many of these features with the laboratory guide, textbooks and atlases. The present chapter was undertaken on systematic gross anatomical approach bearing in mind that the integration of the various organs within the systems allows the animal to live well, while disease conditions can be diagnosed and managed effectively through this didactical approach.

The anatomy of companion animals (cat and dog), livestock animals (pig, sheep, goat, and cattle), sport animal (horse), donkey, poultry and wildlife should be covered in this course.

Objectives

The objectives of this course are to:

1. explain the nomenclature of structures of the organ system and use them in descriptions.
2. describe relative positions of organs in the body and their relationships with one another.
3. correlate the knowledge acquired to diagnostic radiology and surgery courses at the clinical levels.
4. explain the meaning and usage of anatomical terminologies, virtual body planes, terms of positions and directions of different animal species relative to animal body or its parts as this form the basis for medical terminologies and the standard nomenclature in *Nomina Anatomica Veterinaraia (NAV*).
5. describe the topography and structures of the organs in the body of different animal species using the appropriate anatomical terminologies.
6. identify every bone in the skeleton of domestic animals and chickens and explain the differences across species.
7. describe the components of the digestive tract and their roles in food digestion and metabolism.
8. relate the shape and internal modifications of the components of the digestive system to the food habits of a particular species.
9. explain the anatomical features of the heart and blood vessels (arteries and veins) that allow it to function and relate the heart topography to other organs in the thoracic cavity.

Topographical Anatomy (Figures 1 - 2)

The study of Veterinary and Human Anatomy makes use of a number of scientific words or terms most of which came from the Latin or Greek languages. These words are used to show exactly the position and course (direction) of various components of the body e.g., tail, trunk, head, body parts and organs. In addition, some of these words are used specifically for the head and tail, nose, digits and eyelids. For instance:

(a) Terms used for describing **position/direction** for head and cranial structures, trunk, limbs, underside, back, belly, tail, etc:
Cranial- is a term used to describe structures that are located near the head, trunk and tail of the animal species being described,
*Rostral-*is used in referring to structures that are located relative to apex (tip) of the nostrils (in the head region).
Caudal- refers to structures towards the tail. It is reserved for structural features in the head, trunk and limbs that are proximal to the carpus (forelimb) and the tarsus (hind limb).
Dorsal- this descriptive term is used for structures that are located towards the back (stretch of the vertebral column) and used specifically for trunk, head and front of limbs (carpus and tarsus).
Ventral- located near the lower part of the body (belly); it is used mainly for structures on the lower side (underside) of the trunk and the head.
Medial = means located near the center, while *lateral* = is towards the side. They are used in describing the structures of the limbs, trunk and head.
Proximal = refers to towards the trunk of the animal, Also *Distal* = means that it is away from the trunk. They are used for description of forelimbs and hind limbs and other parts of the body which are located close to the body trunk, and away from the main body trunk.
Palmar- refers to structures that are towards the palm (of hand) in the forelimbs, while plantar means the sole of feet in hind limbs. Palmar is used for forelimbs placed distal to the carpal joint, while the term Plantar is used for hindlimbs distal to the tarsal joint.
The term *Axial* = means that it is located near the axis of digits; also, *Abaxial* = which is the opposite of axial means that the structure is away from the axis of digits. The 2 terms are used for the digits.
Also, there are t**erms** used in describing **body parts** and **organ**s and they include some of the following:
External- refers to structures that are located outside an organ or body parts; while the opposite, *Internal-* means those found inside an organ or body/ eyelid of animal species.
Deep= means it is inside of organs or body parts of the head and trunk;
Nasal - means that it is towards the nose, e.g vomeronasal organ (**VNO**,

Jacobson organ). *Inferior* - located below and *Superior* - located above; are used mainly for structures related to eyelid or the eyelid itself; *Temporal* - it is related to the temporal bone; and it is used for eye structures. *Apical* = structures located towards the lip), it is used for digits, nose and tail and even structures in the oral cavity (tongue), while *Oral* - means that it towards the mouth or angle of the mouth (it is for structures in the head).
Superficial (on surface) = is used to describe features that are near the surface of body parts and organs e.g biceps brachii muscle, which is superficial (surface) of the humerus.
In addition, there are **terms** used to describe virtual planes of the animal body:_*median, paramedian, sagittal, dorsal and transverse planes are used in gross anatomy and histology***:**
Median plane – refers to a plane that divides (splits) the body into two equal right and left planes; *Sagittal*- means any plane parallel to the median plane but located further lateral; *Paramedian (parasaggital)* – refers to any plane that is parallel and close to median plan; *Dorsal plane* = means any plane that lies parallel to the dorsal surface; *Transverse plane (axial plane or Cross-section)* - is used to describe a plane that is cut perpendicular to the long axis (median plane). This is a frequently used term in histological sections; *Frontal plane* - refers to a plane that is placed perpendicular to both median and transverse planes. It divides the body into dorsal and ventral portions. Frontal plane is also the same as *coronal plane.*

There are also certain 'prefixes' used in Veterinary Anatomy such as *Infra* - signifying that it is below or beneath (*infraspinatus* muscle and *infratrochlear* nerve); *Supra* = above or over (*supraspinatus* muscle and *supraorbital* foramen).

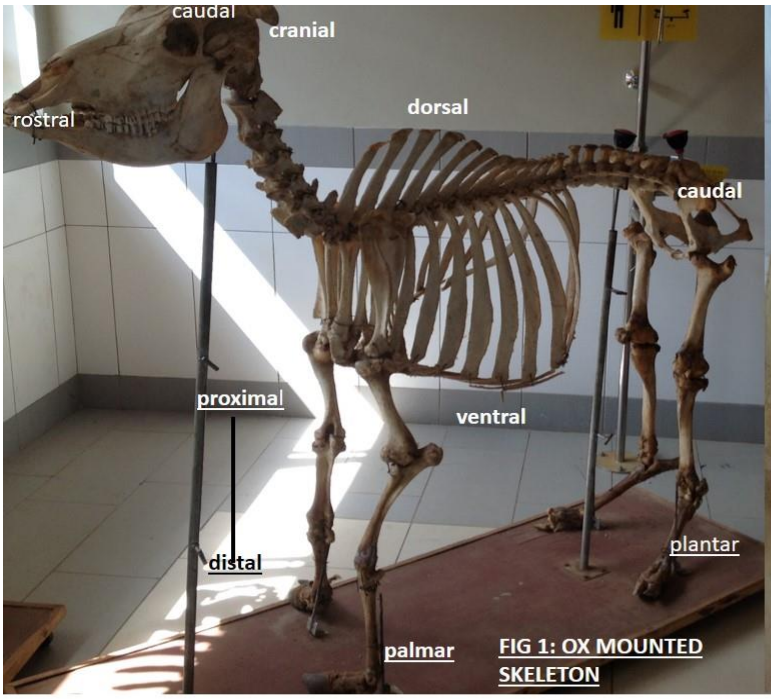


FIG 1: OX MOUNTED SKELETON

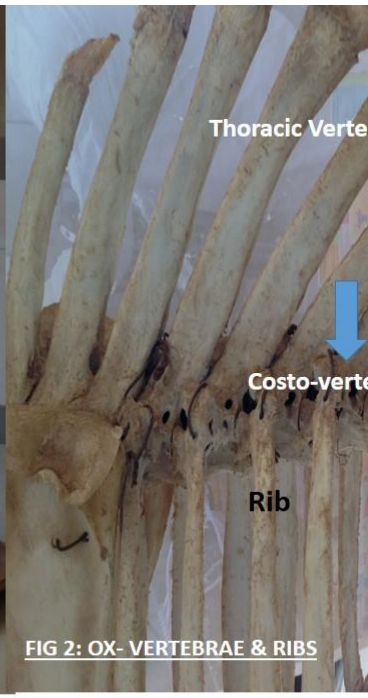


FIG 2: OX- VERTEBRAE & RIBS

Osteology (Figures 3-6)

Osteology means the study of bones that make up the skeleton. Bones represent the hardest structures in the body apart from the teeth. Bones are also classified/named as part of connective tissue like haemopoietic tissue, cartilage, adipose tissue etc. The skeleton refers to the structural 'foundation' made of hard structures (bone) which supports and offers protection to the soft tissues of animals. In the descriptive Veterinary Anatomy lectures, the following are usually considered-;**bone**s, **cartilages,** and **ligament**s. The components of the skeleton originate s from the mesoderm, which is the middle embryonic germ layer. The mesoderm transforms into 3 types of connective tissue s namely embryonic, reticular, and fibrous tissues. All of these tissues are composed of (1) cells (fibrocytes) (2) fluid-filled spaces (3) fibrous component (collagen and elastin).

Axial skeleton – includes all the following- Skeleton of the head: skull, neural part (cranium, neurocranium), facial part (viscerocranium), hyoid bone, mandible, ossicles in middle ear and paranasal sinuses. It also involves naming and identifying the following:

(a) Several openings (foramina) and sutures of the skull with species differences are emphasized and they include *oval foramen, maxillary, orbital fissure, orbito-rotundum* etc.

(b) Vertebral column- It includes the cervical vertebrae (atlas-1st, axis-2nd and 5 other cervical vertebrae), thoracic, lumbar, sacral, and coccygeal/caudal vertebrae.

(c) Skeleton of the thorax, ribs, sternum, ligaments and cartilages. There are some species variations and 'vertebral formula' for each species of domestic animals and a comparison during the practical classes will help in noting them. A comparison of the skull of various domestic animals should be made for the horse, ruminant, dog, cat, pig and avian species. Students should study details of these bones with the aid of atlas and laboratory manual guide**.** Differences in shape and size of the axial and appendicular skeleton account for breed differences in dogs (*dolichecephalic, mesaticephalic and brachiocephalic* breed).

Appendicular skeleton- it is represented by the bones of the limbs and those that connect the limbs to the axial skeleton. It also includes the *pelvic girdle*: The following examples of such bones are discussed.

(a) Thoracic limb (pectoral limb-clavicle) - It is a cartilaginous remnant in the dog, and it is absent in other species. It sequentially consists of scapula (shoulder blade), humerus, radius, ulna, carpal bones, metacarpal bones, phalanges and attached sesamoid bones. Arm (brachium) is humerus; forearm (antebrachium) is radius and ulna; manus is carpus, metacarpus and digits, called forepaw (carnivores); digits is phalanges and associated sesamoid bones. Each digit has 3 phalanges apart from digit 1 (dog) called *dewclaw.*

(b) Pelvic (hind) limb- It is the bone that connects the hind limb to the body. It also consists of hip bones (*os coxae)* which

come together (joint) as pubic symphysis*.* Other bones in the pelvic limb distally are femur, patella, tibia, fibula and tarsal bones arranged in 3 rows in dogs; *talus* and *calcaneus* form the distal row and that make contact with the tibia and fibula), metatarsal bones, phalanges and their sesamoid bones.

Visceral (splanchnic) skeleton - this type of bone is formed in some visceral organs or soft structures e.g *os penis* in the penis of carnivores and *os cordis* in the heart of sheep and cattle.

Avian skeleton- full comparison of the avian skeleton with that of domestic mammals is made to understand the modifications that enable flying in birds. These differences /modifications are evident in the study of internal organs (Splanchnology). In birds, the skeletal modifications that facilitate flight can be seen in the bones of the sternum (keel), thoracic vertebrae of neck, the head (beak, quadrate bone, large orbit, and craniofacial hinge), leg and foot (tibiotarsus, long tendons etc) and forelimb (wing).

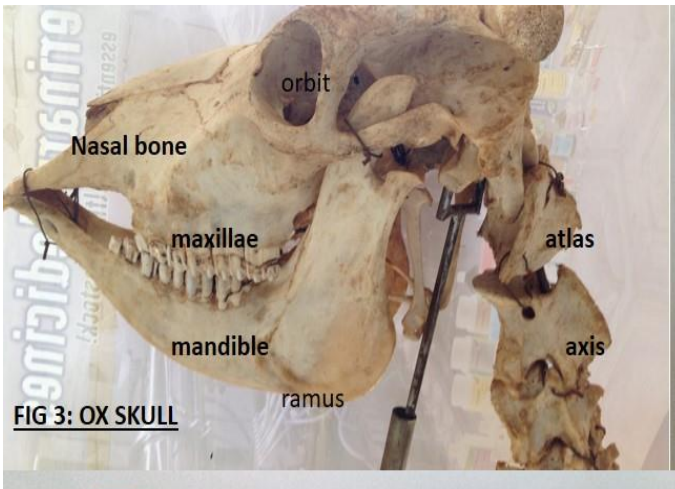


FIG 3: OX SKULL

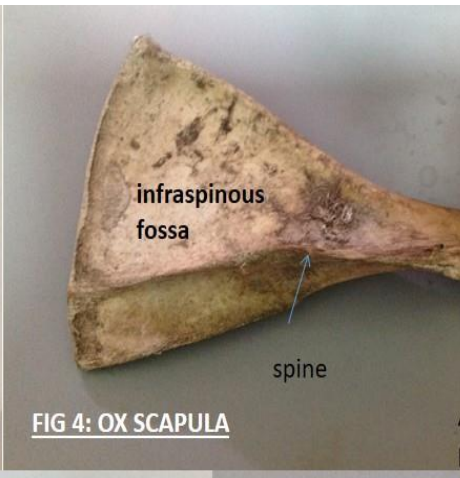


FIG 4: OX SCAPULA

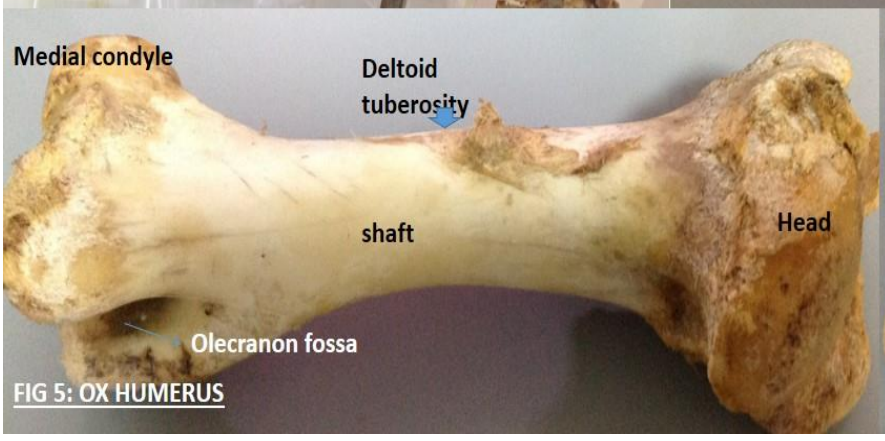


FIG 5: OX HUMERUS

Arthrology (Joints/ Articulations and Ligaments, etc., Figures 7 - 10)

Joints/ Articulation: Generally means the union of two or more bones in the animal skeletal framework. *Arthrology* is defined as the study of joints in the mammalian skeleton. It also involves the knowledge of its function and dysfunction.

Joint classification - It is usually done under several criteria such as: (i) Simple or compound joints. (ii) Structural classification –fibrous,

cartilaginous, synovial etc. (iii) Functional classification-immovable, suture, hyaline cartilaginous joint, slightly movable joint, ligamentous joint, symphysis, freely movable (synovial *articulation/joint*), and gomphosis. Synovial joint is the most common type of joint characterised by mobility (should be able to move), articular cartilage, joint cavity, synovial membrane, and fibrous capsule. Other inconsistent structures that may be present in a synovial joint are- ligaments, menisci, bursa, and synovial sheath.

Synovial (True) Joints

Classification- generally put according to the type of movement produced when muscles acts across joints (i) and number of articulating surfaces (simple and compound joint), (ii) characteristic structure of joints produced by muscles acting on joints which produce variable types of movements (plane joint, ball-socket joint, hinge, pivot, condylar, ellipsoidal, saddle); Examples: hinge-elbow, ball and socket-hip and shoulder, pivot-atlanto-axial, plane-intercarpal/intertarsal, condylar-stifle and temporomadibular joints. This second class produce movements such as extension, flexion, abduction, adduction, circumduction, rotation, dorsal/ventral flexion across joints. Other types of articulations are skull, vertebral column, and intervertebral joints as well as true or synovial joints such as shoulder, elbow, hip and stifle joints etc.

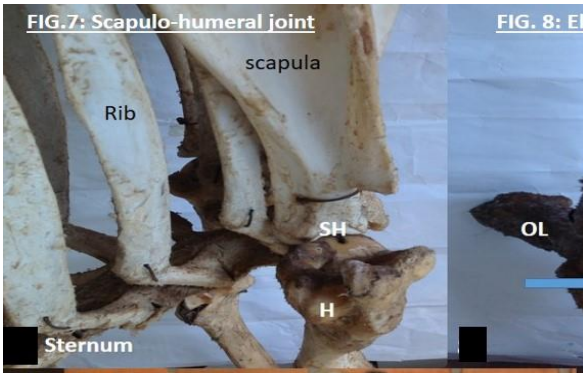
Articulations or joints of the thoracic limb

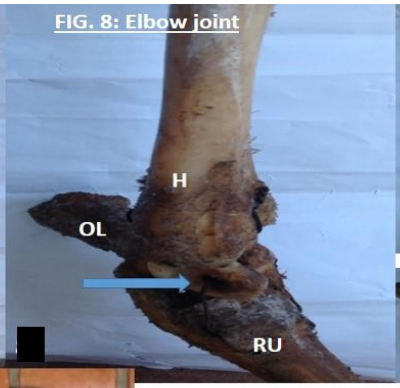
These include: (a) Articulation of forelimb to axial skeleton by group of muscles called a *synsarcosis,* followed by (b) Shoulder joint (c) Elbow joint (d) Radioulnar joints, articulations of the manus- carpal joints, intercarpal joints, phalangeal joints-metacarpophalangeal, proximal interphalangeal (pastern), distal interphalangeal joints (coffin joint). Phalangeal joints of ruminants and horses are highlighted to show the differences and in terminology etc: metacophalangeal joints-fetlock joints, proximal interphalangeal-pastern, distal interphalangeal –coffin joint. The various arrangements of these joints, sessamoid bones, muscle-tendons, sessamoid and their ligaments provide strong support

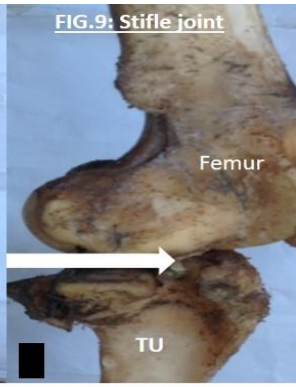
in the much vaunted 'Stay apparatus' in the horse forelimbs and 'Reciprocal apparatus" in the hind limbs. It is to a lesser extent present in the cattle.

Joints of the pelvic limb

It begins from the (a) Sacroiliac joint which is a somehow relatively immovable junction of the ilium and wings of sacrum (a synchondrosis). (b) coxofemoral or hip joint which represent a typical ball-socket joint (c) stifle joint which is a condylar joint that functions as hinge joint with small rotational ability (d) femorotibial joint (e) femoropatellar joint (f) tibiofibular joint (g) Pedal joint-tarsal or hock joint comprised of tarso-crural joint, proximal intertarsal joint, centrodistal joint, tarsometarsal joint, distal intertarsal joint and their complex ligaments that provide passive stay apparatus. Clinical reference of the joints in disease and fracture are many and include- fracture of tarsus, osteoarthritis –'bone spavin' (horse), hip dysplasia, luxation of the hip and fractures of the hip-large dog breeds, cruciate ligament rupture (dogs).







Some joints of the vertebral column and limbs

Fig 7: SH-scapula humeral joint H-humerus

Fig. 8: Elbow joint (arrow) - OL-olecranon bone, humerus, Radius and ulna (RU)

Fig. 9: Stifle joint (arrow), TU-tibia and fibula

Fig 10: represent a typical synsarcosis joint (arro scapula (S) and vertebral column (V)

Myology (Muscular System – Figure 11)

The mammalian muscular system consists mainly of skeletal (striated) muscles in the body, which induce movement of a region of the skeleton. Also, there are smooth and cardiac (heart) muscles. Striated muscle (skeletal) is firmly attached to skeleton which is under conscious control or voluntary (being aware of its action). They produce voluntary movements of the trunk, limbs, and head regions. Muscle fibres are acted upon (stimulated) to contract by nerve impulses being carried by nerve fibres in muscle bundles. Muscle tissue is most times under a certain level of tension (muscle tone). It is worth noting that each area of the body has an array of specialised muscles made to bring about specific types of movement which is important for the normal function of the animal. The topic 'myology' entails an overview of classification of muscles and their functions, brief description of muscle development, principles of nomenclature of skeletal muscles, skeletal muscle as an organ, connective tissues associated with skeletal muscles, principles of classification of skeletal muscles, gross appearance of skeletal muscles and parts of a skeletal muscle (gross) is explained to understand basic mammalian kinetics. Adequate understanding of the relationship between muscle groups, skeleton, blood vessels, nerves and lymphatics is appreciated during the dissection classes. Other structures that are associated with muscles and joints are sesamoid bones, synovial tendon sheaths, bursae, and fascia. It is worth noting that muscles of the body act in opposing groups (agonist and antagonist) to produce a range of movement (e.g., flexion/extension). For example, biceps brachii (flexor) and triceps brachii (extensor) of the elbow joint.

Specific Myology – muscles of different body regions.

Head and neck muscles: These include muscles of facial expression (mimetic muscles), muscles of mastication, lingual muscles, hyoid muscles (muscles associated with the hyoid apparatus), pharyngeal muscles, laryngeal muscles, and eye muscles. There are also muscles of the neck whose cervical portions cover organs of the neck. The `*Triangle of Viborg'* in horse- boundaries, contents and clinical relevance

in equine practice is quite important in the surgery of the neck and laryngeal region.

Muscles of the trunk: They include muscles associated with vertebral column and are divided into; *Epaxial* muscles (lateral column-iliocostalis; middle column-longissimus; medial column-tranversospinalis) situated above the transverse processes of the vertebrae and their subdivisions. *Hypaxial group of muscles*: including thoracic wall involved in respiration (external and internal intercostal muscles, rectus thoracis, serratus dorsalis) and abdominal wall muscles. Attention should be given to their *origin*, *insertion*, *fibre orientation*, *action, blood supply, functional innervations,* and *clinical relevance*.

Muscles of the forelimb: these are muscles of the shoulder girdle that connect the forelimb to the trunk (extrinsic muscles). Intrinsic muscles are those of the shoulder, elbow, carpal and digital joints.

Muscles of the hindlimb (pelvic girdle muscles) are those that act on the hip, stifle, tarsal and digital joints. Note the femoral triangle in carnivores i.e., their boundaries, contents, and clinical relevance. A review of the comparative myology of different species should be noted.

Avian myology: The following should be briefly explained and dissected without going into great details: muscles of adaptation to flight in birds, median and radial nerves, ulnar (wing) vein in the forelimb and their Veterinary importance. The biceps femoris, semitendinosus, semimembranosus, sciatic nerve etc in the hind limb and their clinical importance should be noted as in other domestic animals.

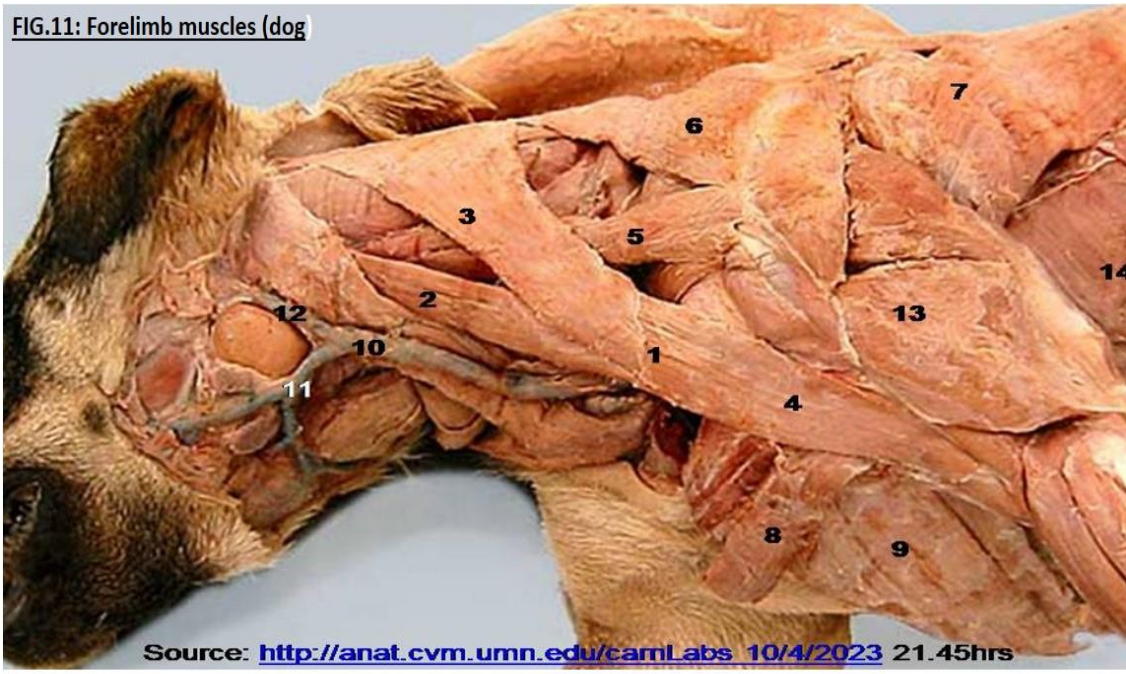
Various Types of fascia and muscles are provided below with examples in each type:

Fasciae-The head and trunk are covered by large sheets of connective tissue called fascia and they occur at certain regions namely: (a) superficial fasciae of the head, neck and trunk; (b) deep fasciae of the head, neck and trunk; (c) thoracolumbar fascia; (d) spinocostotransversal fascia (e) deep fascia of the tail.

Cutaneous muscles of the head- these include the following- cutaneous muscle of the face, superficial sphincter muscle of the neck, deep sphincter muscle of the neck, and frontal muscle.
Cutaneous muscles of the neck- such as superficial sphincter muscle of the neck, platysma muscle, deep sphincter muscle of the neck, and cutaneous muscle of the neck.
Cutaneous muscles of the trunk- abdominal portion of the cutaneous muscle (cutaneous trrunci), cutaneous omobrachial muscle, prenuptial muscles and supramammary muscles.
Muscles of the head- The muscles of the head can be grouped based on their development origin, their innervation or their function: (a) Facial muscles-(i) muscles of the lips and cheeks: orbicular muscle of the mouth, incisive muscles, nasolabial levator muscle, levator muscle of the upper lip, canine (caninus) muscle, depressor muscle of the upper lip, depressor muscle of the lower lip, levator muscle of the chin, zygomaticus muscle and buccinator muscle. (ii) Muscles of the nose: apical dilator muscle of the nostril, medial dilator muscle of the nostril, lateral muscle of the nose and transverse muscle of the nose. (iii) Extraorbital muscles of the eyelids -orbicular muscle of the eye, levator muscle of the medial angle of the eye, levator muscle of the lateral angle of the eye and malar muscle (iv) Muscles of the external ear: scutular muscle, parotidoauricular muscle, caudal auricular muscles, dorsal auricular muscles, rostral auricular muscles, deep auricular muscles, and it also includes styloauricular muscle.
(b) *Muscles of the nostrils (nose)*- They are poorly formed in carnivores in pigs and well developed in the horse and ruminants and includes lateral muscle of nose and medial dilatator muscle of nostril. (c) Muscles of eyelids-orbicularis oculi muscle of eye, levator muscle of medial and lateral angle of the eye and malar muscles. (d) Muscles of the external ear- scutular muscle, caudal auricular muscle, parotid-auricular muscle and dorsal auricular muscle (e) Mandibular muscles- mandibular muscles consists of muscles of mastication and superficial muscles of mandibular space: (i) mastication- masseter, medial and lateral pterygoid muscle, temporal muscle (ii) superficial- this includes the

easily identified digastricus muscle and mylohoid (mylohyodeus) muscle.
Other classes: include-muscles of the neck-splenius, scalenus and muscles of hyoid apparatus. *Muscles of the dorsum (back)* include trapezius, brachiocephalicus, sternocephalicus, omotransversaruius, latissimus dorsi (broadest), superficial pectoral and sternocleidomastoideus. Muscles of back and neck (sacrospinal and lateral systems) are numerous and important for support of the body. Others are muscles of thoracic wall and respiration, muscles of abdominal walls which support abdominal and some pelvic organs and muscle of the tail. Students are expected to identify these muscles in the practical classes with the demonstrators and lecturers instructing them. The muscles of the thoracic and pelvic limbs which allow the animal bear weight and move around are also important and adequate attention should be paid to them with the aid of dissecting guides, textbooks and atlas (**a picture speaks a thousand words!)**

FIG.11: Forelimb muscles (dog



Extrinsic muscles of forelimb of dog. 1. Brachiocephalicus m. with mastoid (2) and ce parts, cleidobrachialis m. (4). Others are omotransversarius m. (5); trapezius m. (6), latis dorsi m. (7), and superficial (8) and deep (9) pectoral mm. Note the **external jugular** (1 linguofacial (11) and maxillary veins (12),Triceps brachii m (13) and abdominal muscle

Respiratory System (Figures 12 – 13)

The air breathing apparatus, the *respiratory system* is important in gaseous exchange between the atmospheric air and blood in the body systems. If no such exchange exists, then the animal will die of anoxia due to lack of oxygen. It is divided into respiratory passages (which we can see grossly in the thoracic cavity) and gaseous exchange (histology-slides under microscope). The air passages are made up of the following organs from the outside: external nose-*where the air enters*, then into nasal cavity, nasopharynx, larynx, trachea, bronchi, and lungs (a lobated structure). The sites of gaseous exchange (this is where air

carrying oxygen enters the blood vessels) within the lungs and are usually not visible grossly, they are: *respiratory bronchiole, alveolar ducts, alveolar sacs, and alveoli.* Details of the following are serially explained to understand the flow of air and other substances for function beginning from the upper respiratory tract (nose, nasal cartilages, nasal vestibule, nasal cavities, nasal conchae, nasal meatuses, paranasal sinuses, and lower respiratory tract (larynx, cartilages of larynx starting from epiglottis to cricoid, laryngeal cavity), the laryngeal articulations, ligaments and muscles are taken under myology. The trachea (species differences exist in number of rings and arrangement) in relation to trachea muscle is important (dog, pig, ox, and horse). The trachea divides (into two) into primary bronchi before entering the lung (right and left lungs**).** The location, shape, lobation, and lobulation (cranial, caudal, middle, and accessory lobes) and topographical relationship of the lungs and its pleura to the heart, ribs and mediastinum is important and demonstrate species variations. The lungs show variable divisions of the bronchus called 'bronchial tree' (like the trunk, branches, and the leaves of tree) of the bronchi within the lung. The bronchial tree divisions are important from the respiratory passage to sites of gaseous exchange. There are species differences in lobation and size of the lungs and air conducting passages. The blood supply, lymphatic and innervation are discussed under cardiovascular and lymphatics systems. In addition, the respiratory structures can be separated into the respiratory passages (tubular passages) and sites of gaseous exchange (to be covered adequately under histology). The respiratory passages comprise the following organs: external nose, nasal cavity, nasopharynx, larynx, trachea, bronchi, and lungs. The exact locations of gaseous exchange within the lungs are named sequentially to be respiratory bronchioli, alveolar ducts, alveolar sacs, and alveoli. Generally, the *upper respiratory tract* begins from the nose which is made up of the external nares and their related nasal cartilages, the nasal cavity with the hollow passage (nasal meatus) and conchae (cartilage or bone scrolls) and the paranasal sinuses (which are ordinary diverticular of the nasal cavity). The external nares are basically supported by the nasal cartilages, which differ in form, size

and number depending on the species. The nostril forms the opening of the nasal cavity and surrounds the nasal vestibule. The nasal cavity runs from the nostrils towards the cribriform plate of the ethmoid bone (at the frontal base of the skull/brain) and is divided by the nasal septum into right and left sides (2 nasal cavities). The nasal conchae are cartilaginous structures inform of scrolls or may be ossified, covered with nasal mucosal epithelium (respiratory or olfactory) which occupy most of the nasal cavity. They are usually 3-5 in number and show species variations (first endoturbinate and second endoturbinate, dorsal, middle, and ventral). There are also three clefts or meatuses between them. The paranasal sinuses (frontal, maxillary, ethmoid, sphenopalatine, lacrimal e.t.c) are diverticula (excavations into the bones) of the nasal cavity. These sinuses create air-filled cavities between external and internal lamina of bones of the skull, and sometimes can be infected by pathogens. The *lower respiratory tracts* consist of larynx, trachea, and lungs. Larynx is a tube-shaped cartilaginous structure with some intervening muscles that joins the pharynx to the trachea. It protects the passageway to the trachea, and it helps to prevent the intake of foreign material (food particles, dust, water etc) into the lower respiratory tract. It plays a role in voice production (vocalization-e.g barking in dogs). Furthermore, the skeleton of the larynx consists of these orderly arranged *laryngeal cartilages*: epiglottic cartilage, arytenoid cartilage, thyroid cartilage, and cricoid cartilage. Functionally, epiglottis cartilage guards the opening into the laryngeal cavity during swallowing. The laryngeal vestibule is a prominent folding of the mucosa in horses, dogs, and pigs. Also, trachea runs from the cricoid cartilage of the larynx to its division into two tubes as it enters the two lungs. It is made up of a serially arranged C-shaped cartilages strongly joined by ligaments. However, the number of tracheal cartilages differs among domestic species (sheep: 48-60; pig: 29-36, ox: 46-80; dog: 42-46). The right and the left lung are a mirror image of the other (grossly) and relate with each other at the bifurcation of the trachea. The lung has a dorsal and ventral border. There are also costal, diaphragmatic, and mediastinal surfaces. The cardiac notch is the point where the lungs contact thoracic walls

laterally. A thin serous membrane (pleura) surrounds the lungs. A small liquid-filled space is located between visceral pleura (surrounds the lung tissue) and parietal pleural (lines thoracic walls), it serves to reduce friction during respiratory cycles. The whole lungs are made up of parenchyma and interstitium (stroma). Pulmonary parenchyma is where the exchange of oxygen from the atmosphere and release of carbon dioxide from animal blood takes place. After the division of the trachea, the principal bronchus (left and right) divide within the lungs into series of graded branches of channels into two-branching patterns or three-branching patterns (so called 'bronchial tree'). Also, each new division is smaller in diameter, thus forming the 'bronchial tree'. The 'bronchial tree' can be functionally split into two parts (1) *Respiratory passageways* - which is composed of: principal bronchi, lobar bronchi, segmental bronchi, sub-segmental bronchi and terminal bronchioli, (2) *Sites of gaseous exchange* within the lungs include: respiratory bronchiole (there are also secondary and tertiary bronchioles), alveolar ducts, alveolar sacs, and pulmonary alveolus. The left and right lungs are divided into lobes. In terms of lobation, the left lung is divided into a cranial (apical lobe) and a caudal lobe (diaphragmatic lobe). In addition to cranial and caudal lobes the right lung possesses a middle and an accessory lobe. In some species the cranial lobes are further subdivided into cranial and caudal parts ('kinking of lobes'). The lungs show species variation in lobation and bronchial tree patterns. There is a tracheal *bronchus* which takes off directly from trachea before its division, and is present in ruminants and pigs, it supplies the right cranial (apical) lobe. The identification of lungs of individual species is most easily based on the degree of lobation and lobulation. The lungs of ruminants and pigs are remarkably lobated and lobulated. Lungs of the horse show almost no lobation and very slight lobulation externally. Those of carnivores are very deeply divided into lobes but show little external evidence of lobulation.

The respiratory system is important in several diseases and conditions (rhinitis, pneumonia, laryngitis, bronchitis) and clinical diagnostic/surgical procedures (laryngoscopy, tracheostomy, thoracotomy, bronchography and laryngography. The lungs should be

examined very well during meat inspection for evidence of tuberculosis lesions especially in cattle.

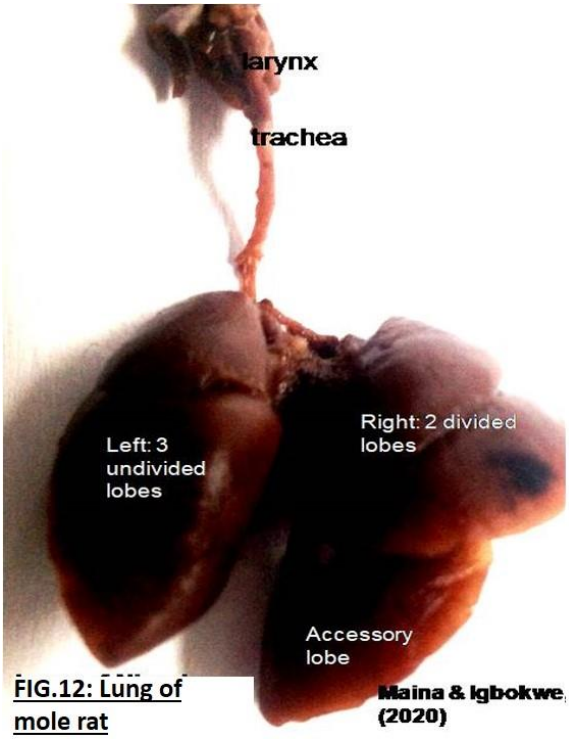


FIG.12: Lung of mole rat

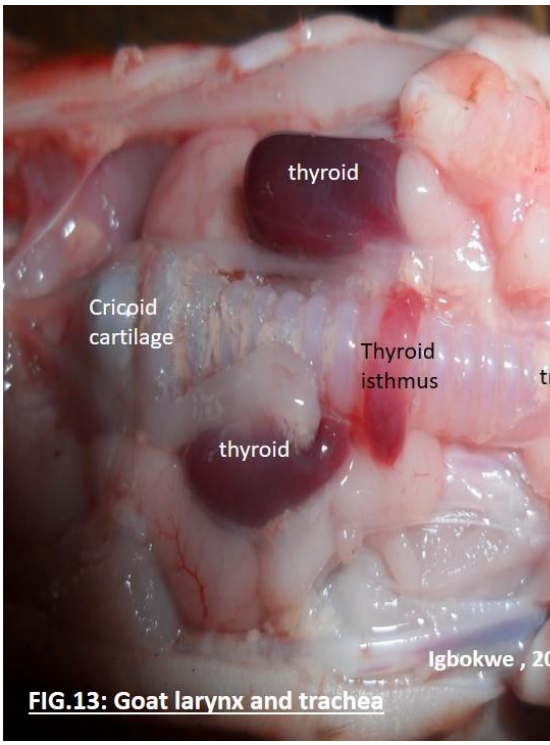


FIG.13: Goat larynx and trachea

Digestive System (Figures 14-19)

The digestive system is significantly involved in the breakdown of ingested food into smaller portions, so that it can be used by the body for energy (to move, fly, eat etc), growth and cellular renewal in various tissues/organs. It performs this function through mechanical mixing, enzyme action and digestive acid secretion. Functionally, the organs of this system can receive food during grazing and in feedlots, mechanically and chemically breaking it down into its component molecules and thereafter absorbing them in the small intestines. It also voids unabsorbed products, and they are voided as residues

(faeces/droppings). The various cells of the gastrointestinal tract are significantly important for this process, and some also secrete hormones to facilitate digestive action. Plentiful blood vessels, nervous tissue, blood, and lymphatics all play important function in digestion. Embryologically, the digestive system is basically formed from the endoderm, which is a primordial germ layer that lines the yolk sac in the early development process. The connective tissues and muscles that form part of the digestive tube are derived from the mesoderm. The digestive apparatus passes through stages of foregut (forms pharynx, oesophagus, and stomach etc), midgut (other segments of small intestine, cecum, and greater parts of large intestine) and hindgut distal portion of colon, rectum and parts of urogenital tract after partitioning). It is then separated into specific segments with varying functions in the adult animal. Details of this transformation are covered under the embryology part.

Functionally, the digestive system engages in prehension (i.e capturing/chewing/grazing), digestion (mouth and stomach), absorption of food (small intestines), and elimination of solid waste material (large intestine). Basic components of the digestive system include: the mouth and pharynx. It also includes the tubular oesophagus and stomach, small intestine, large intestine, and anal canal. The digestive system can also be explained as consisting of the alimentary canal, that stretches from the mouth to the anal opening. It also includes accessory digestive glands (liver, gall bladder and the pancreas) and salivary glands. These accessory organs release very important digestive products into the alimentary canal that control very important metabolic processes like carbohydrate (glucose) fate. Generally, the parts of the digestive tract when orderly listed following an ingested food will include oral cavity or mouth, lips, tongue, teeth, pharynx, oesophagus, stomach, small intestine (duodenum, jejunum, ileum), large intestine (caecum, colon, rectum, and anus). There are also several accessory glands without which the digestive process cannot be completed, and these glands include: salivary glands (parotid, mandibular sublingual and zygomatic etc), gall bladder and liver. Using the term mouth (*oris*) does not mean only the cavity and its

walls, but also involve the conspicuous anatomical structures that project inwards (teeth, tongue) and those secreting products (salivary glands) into it. The main role of the mouth include: prehension ('eating/chewing process'), mastication and insalivation of food. The mouth also plays a role in aggression and defence (carnivores), and even in sound formulation (dogs-barking & humans-songs etc). In some mammalian species, it serves as alternate breathing airway whenever the nose is obstructed (impaired) in health and in disease. The oral cavity is rostrally (recall it is a head structure) bordered (bounded) by the lips, cheeks, hard palate and caudally it communicates (makes contact) with pharynx. The tongue (lingua) is a highly mobile muscular organ that fills major portion of the oral cavity. It equally goes into the oropharynx. It has a firmly attached root (by hyoid apparatus) body and an apex which is free in domestic species but not so in birds. It is used in capturing (prehension etc grazing cattle and sheep), lapping, grooming, and manipulating food inside the mouth and for swallowing. It is involved equally in speech (voice) articulation. Anatomically, salivary glands are classified into *major* (parotid, mandibular, sublingual etc) and *minor* salivary glands. The *minor salivary* glands are namely: labial glands, buccal glands, and lingual glands. They are located under the mucosa in cheeks (buccal), palate (palatine), tongue (lingual) and sublingual floor of the oral cavity. The masticatory structures are the teeth and surrounding gums, masticatory muscles, and strong temporo-mandibular joint. Dentition is quite important in veterinary clinical anatomy, medicine, and surgery. There are variations in dental formula of animals. The pharynx is a funnel-shaped passage with irregular narrow boundaries. It is also muscular and membranous passage that joins the oral cavity with oesophagus, and the nasal cavity with the pharynx (*oropharynx; nasopharynx*). The pharynx has 3 parts namely: nasopharynx, oropharynx, and laryngopharynx. It is a singular passage for which both air and ingested food particles can pass through. Following the oropharynx is oesophagus, which is a narrow expansible tube that connects pharynx and stomach. The oesophagus is also called *gulle*t. It starts by situating dorsal to cricoid cartilage of the larynx and terminates at the cardia of the stomach. Topographically, the stomach

is wedged between oesophagus and small intestine. In domestic mammals, the stomachs demonstrate considerable variation in morphology and spread of the different types of mucosa lining of the stomach. It is classified into *Simple stomachs* and *compound stomachs*. Specifically, cats and dogs possess *simple, glandular stomachs.* The stomach of horse and pig is classified into *simple, composite stomachs*; here much of the stomach is covered by glandular mucosa and a small fractional cranial part by non-glandular mucosa. Major internal divisions of simple stomach as seen are cardiac portion, fundic portion, body (corpus) and pyloric portion. Ruminants possess a *complex, composite stomach*, that consists of four compartments, three (3) of which (rumen, reticulum, omasum) are lined by non-glandular mucosa and (one) (abomasum) is covered internally by glandular mucosa. The stomach position is closely related to the embryological formation of greater omentum and lesser omentum. This location of the apron-like mesentery allows the connection of the stomach to nearby organs such as spleen and the liver. Generally, mammalian intestine represents the caudal part of the digestive tract. It begins from pylorus and continues to the anal opening. It is divided into small intestine, which stretches from pylorus to caecum (other divisions such as *duodenum, jejunum* and *ileum* are distinguishable especially under the microscope) and the large intestine runs from the caecum to the anus. The small intestine consists of three parts: the duodenum (most proximal part), the jejunum (longest part and most mobile) and the ileum (a short terminal part). In addition, large intestine is comprised of blind caecum, colon, and rectum. Furthermore, the colon is split into ascending, transverse, and descending colon. When it enters the pelvic region, the descending colon transforms as the rectum, which runs terminally as the most dorsally located of the pelvic visceral structures. A good part of the rectum is suspended (held in upward position to hang) by the mesorectum. Finally in the GIT, a short *anal canal* is the terminal part of the alimentary canal that opens to the outside with anus. This opening to the outside is guarded by internal and external anal sphincters. There are species differences in the caecum of horse, pig, and ruminants in relation to 'ileum- caecal-colic' openings (e.g horse

has a separate ileal orifice and caecolic orifice). The caecum in horse and pig has bands (*taenia*) and haustrations with differences in numbers. The ascending colon in horse has limbs and flexures. It also has bands and sacculations. The colon in pig is cone-shaped and thrown into centripetal, central flexure and centripetal turns; that of ruminants (ascending colon) has sigmoid flexure, two centripetal turns and two centrifugal turns. The liver is a large endocrine gland which is situated in the most cranial part of the abdomen. It is located just caudal (immediately) to the diaphragm and cranial to the stomach and intestines. The liver is an outgrowth of the primitive duodenum during mammalian embryonic development. The liver varies in size, weight, form (lobation), position across mammalian species. The liver plays very important role in blood formation (foetus), bile secretion, it removes waste products and stores fat amongst other functions. Prominent fissures divide the liver into four basic lobes and two processes. The right and left lobes maybe divided into medial and lateral lobes (as seen in carnivores and pigs). The left lobe is placed to the left of the median plane except in ox, goat, and sheep (ruminants) which have the large rumen that pushes the liver to the right side of the body. Quadrate lobe- is present between the right and left lobes, but ventral to the *porta of the liver*. In addition, the caudate lobe is located dorsal to the porta of the liver and has the caudate and papillary processes. The pancreas is a roughly V-Shaped gland with 2 lobes joined by a body and closely related to the cranial flexure of the duodenum (pancreatic duct drains into the dudodenum). It has exocrine and endocrine. Exocrine deals with production of pancreatic juice / enzymes. Pancreatic enzymes functions in the breakdown of carbohydrates, fats, and proteins. Its exocrine part plays a key role in production of hormones that regulate blood sugar-insulin and glucagon. Gall bladder is sac that stores and concentrate bile produced from the liver (excess of it). Bile functions in the breakdown and lubrication of food going into the duodenum from the stomach. Topographically, gall bladder is placed in the space between the quadrate lobe and the right medial lobe of liver (horse and rats do not have it) and therefore no cystic duct. The avian gastrointestinal tract is different from that of domestic mammals in

many ways that reflect the flying habit and food items consumed. It is made of oral cavity, tongue, oesophagus (cranial and caudal parts), crop, proventriculus, gizzard (ventriculus), duodenum, jejunum, ileum, caecum, colon and vent (Figs. 15 & 16).

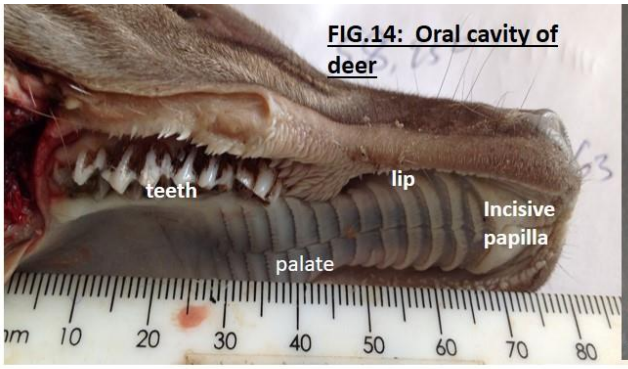


FIG.14: Oral cavity of deer

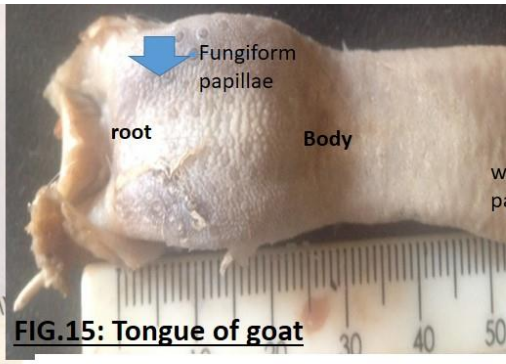


FIG.15: Tongue of goat

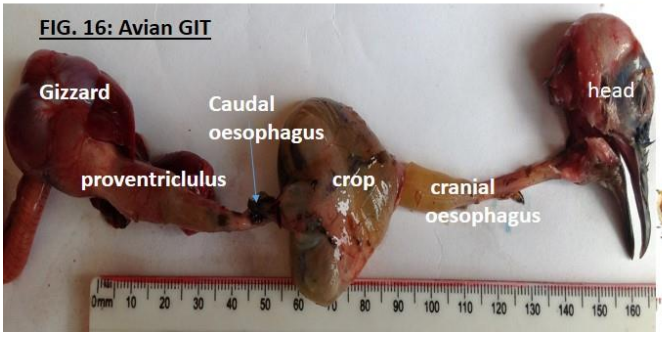


FIG. 16: Avian GIT

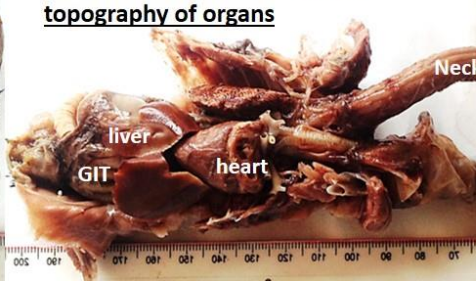


FIG.17: Avian viscera showing topography of organs

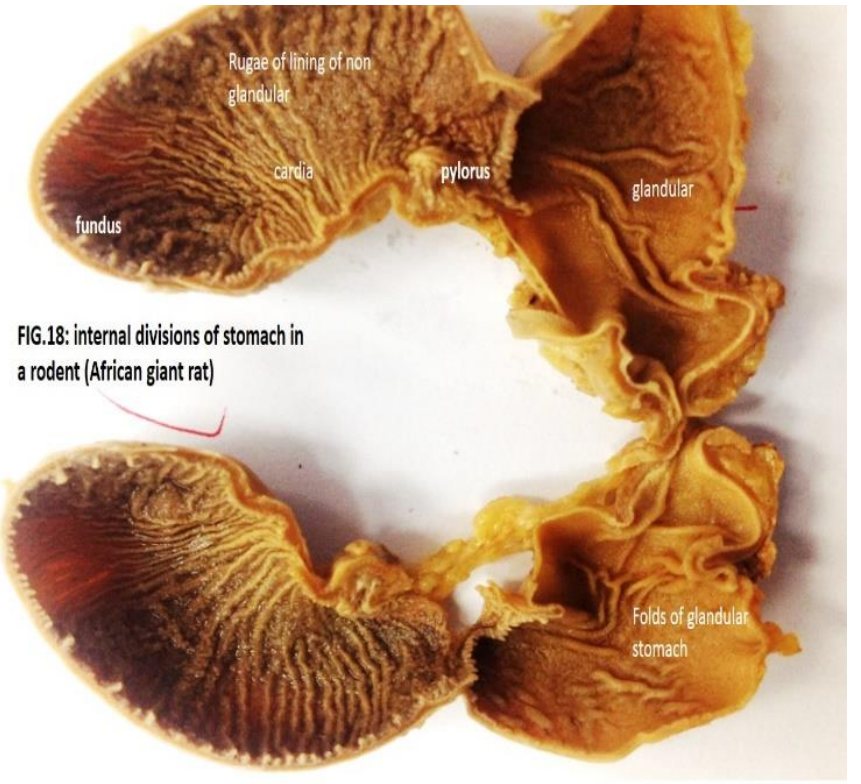


FIG.18: internal divisions of stomach in a rodent (African giant rat)

FIG.19: Gastrointestinal tract of a wild ruminant (deer)

General Plan of Circulation, Heart, Arterial, Venous and lymphatic systems (Cardiovascular System, Figure 20)

The cardiovascular system is made up of the heart, blood vessels and lymphatic vessels. Physiologically, the heart constitutes the strong muscular pump of the cardiovascular system. A major component, which is blood vessels, consists of arteries, capillaries and veins that form a continuous (channel) system in which blood circulates throughout the mammalian body. Functionally, blood carries oxygen and other molecules necessary for the normal cell metabolism, to the tissues and in turn, moves cell products from the tissues to the liver, the kidneys and the lung for metabolism and excretion. In addition, blood vessels and the chambers/compartments of the heart form a

single cavity, through which the blood goes round continuously (circulatory process), due to the pumping action of the heart. Functionally also, the heart drives blood in two ways namely: *pulmonary circulation* (right side of the heart to the lungs) and systemic circulation (through the left side to the heart walls/whole heart and then to other parts of body through aorta). Considering the importance of the heart in animal survival, we pay attention anatomically to the heart by noting: (i**)** major vessels/chambers of the heart such as caudal vena cava, cranial vena cava, right ventricle, right atrium, pulmonary trunk, pulmonary arteries, pulmonary veins, left atrium, left ventricle and aorta. We also carefully look at (ii) the conducting system of the heart including: atrio-ventricular (AV) node, sinoatrial (SA) node, atrioventruclar bundle and marginal bands (moderator band).

Structurally, the heart is made up of external fibrous covering (pericardium). It has two atria and ventricles. The shape and topography vary in species. There is an apex and a base. There are several compartments of the heart (internal and external). It has several internal structures which should be noted carefully by students in the practical classes. The conducting system, blood supply and lymphatic should be explained in relation to heart function. There are arteries of pulmonary and systemic circulation. Also, the cranial branches of the aortic arch are-brachiocephalic artery, subclavian, vertebral artery, superficial cervical, deep cervical arteries, axillary artery and distal branch (brachial artery). The carotid trunk must be closely studied. Branches of the thoracic and abdominal aorta should be traced and known. Similarly, the branches of the caudal and cranial vena cava should be examined. The brachiocephalic trunk from the heart continues as right subclavian after giving off (branches) right and left common carotid arteries. However, the common carotid arteries have been discussed in the chapter of head and neck. The branches of subclavian artery are vertebral, costocervical, superficial cervical, internal, and external thoracic that supply blood to the regions as their names depict. The subclavian continues as axillary artery in the axilla. The axillary artery has been discussed in the chapter dealing with the forelimb. The aorta continues backward as descending aorta-thoracic

and abdominal aorta. The thoracic aorta gives off dorsal intercostal arteries and broncho-esophageal trunk. The thoracic aorta then passes through hiatus aorticus in the diaphragm into the abdomen as abdominal aorta. The abdominal aorta has parietal and visceral branches. The parietal branches-lumbar arteries, phrenicoabdominal trunk, external and internal iliac, median sacral arteries supply blood to abdominal muscles, pelvic wall and hind limbs. The visceral branches paired- renal arteries and testicular/ovarian. The unpaired visceral branches are celiac-stomach, liver and spleen; cranial mesenteric-small intestine, cecum, ascending colon and transverse colon; and caudal mesenteric – descending colon and rectum. The systemic veins including the caudal and cranial venacavae carry blood into the right atrium of the heart. The veins that join in the formation of cranial vena cava are internal and external jugular veins, vertebral, internal thoracic, and right azygous veins. The caudal vena cava is formed near the pelvic inlet by the fusion of the internal iliac (drains the pelvic wall and organs) and external iliac veins which supply/drain the hindlimbs. It receives branches-lumbar, renal, etc and merges into vena caval fold in the liver. The caudal and cranial mesenteric, splenic, gastro-duodenal veins drain into the portal vein in the liver and the hepatic veins into caudal vena cava. The caudal vena cava goes through foramen vena cavae in the diaphragm to thoracic cavity and drains into right atrium of the heart. The above description is for dog; there are species differences that should be explained. The clinical importance of the above organs of the cardiovascular system in health and disease should be emphasized. Foetal circulation should be explained under embryology.

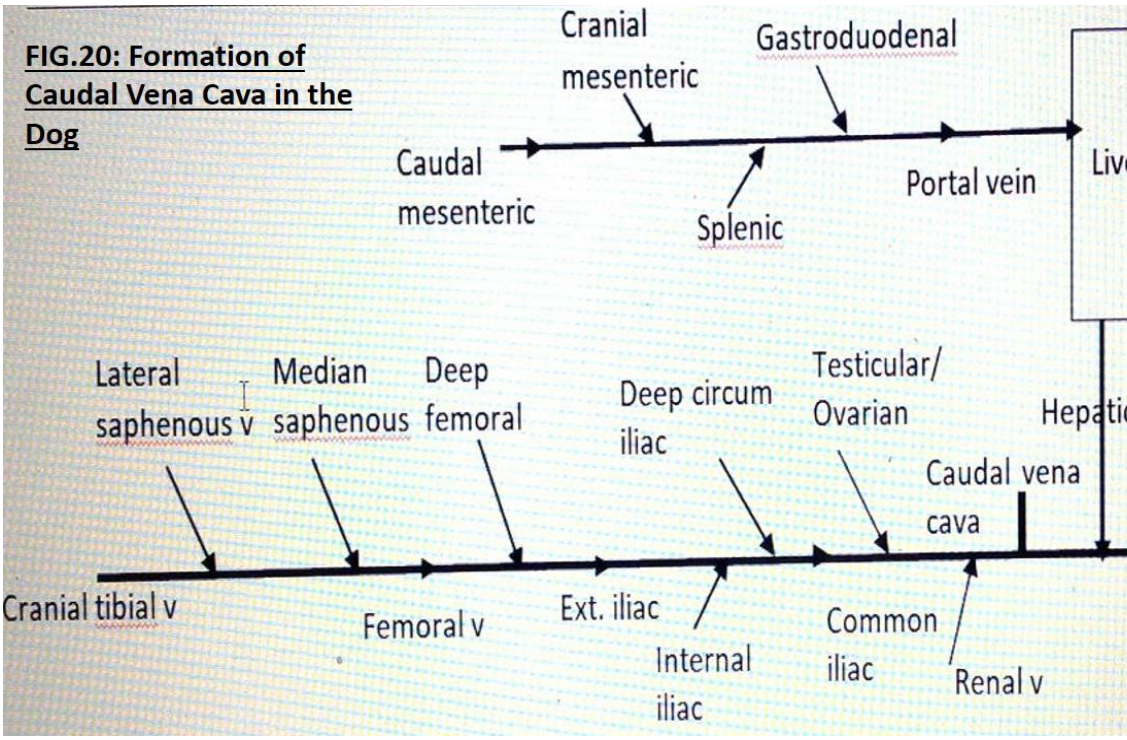


FIG.20: Formation of Caudal Vena Cava in the Dog

Lymphatic System

The lymphatic system is a second vascular network that is found in the body along with blood vessels but carry lymph instead of blood. The lymph vessels are responsible for integrity of the system. The lymphatic system functions in specific and non-specific immunity along with the lymphatic organs. It is also involved in engulfing of foreign particulate materials. In addition, it also moves fats from the digestive system to the circulation through *lacteals.* Lymph is composed mainly of proteins and similar in content to body plasma. It also has lymphatic cells that are often captured by lymph nodes.

Lymphatic tissue and organs

Anatomically, the lymphatic system is made up of lymphatic tissues and vessels. It brings back protein-rich fluid called lymph (which is almost like blood plasma) to general blood circulation. The system functions in

lymphocyte and anti-body production, taking up (engulfing) particulate matter and carrying fats that come from digestive system (in *lacteals*) to the general circulation. The lymphatic tissue plays a major role in defence with fixed cells (reticular cells) and mobile cells (lymphocytes, plasma cells and macrophages). Also, the lymphatic system is made up of both lymphatic vessels and lymphoid tissue that are scattered in many regions (areas/organs) of the body except in the central nervous system and bone marrow. It is made up of:

(1) *Lymph capillaries*- these are thin-walled, fragile tubes that form networks in the tissues. Inside the villi of the small intestine, the lymph capillaries are called lacteals and are responsible for taking up the products of fat digestion. Lymphatic capillaries coalesce to form the larger lymphatic vessels which enter the lymphatic ducts**.**

(2) ***Lymphatic ducts*-** the lymphatic vessels go into the larger lymphatic ducts that drain lymph into blood vessels heading to the heart and into the general circulation. Morphologically, major lymphatic ducts include (a) *right lymphatic duct* – it is the thinner of the two major ducts and carries lymph from the right side of the head, neck and thorax, and right forelimb of all domestic animals. It pours the contents into the right side of the heart through either the right jugular vein or cranial vena cava. (b) Thoracic duct – this is the major lymphatic duct and gathers blood from the remaining part of the body. This duct arises in the abdomen in an enlarged form, where it is referred to as *cisterna chili*. It collects lymph contents from the abdomen, pelvis, and hindquarters. It goes through the opening of the aorta in the diaphragm (aortic hiatus) and enters the thorax, where it is now referred to as *thoracic duct.* It captures lymph from the left side of the upper body and left forelimb. The thoracic duct pours its content into either the jugular vein or cranial vena cava, near the heart**.**

(3) *Lymph nodes* - are collections (masses) of lymphoid tissue located along the lymphatic vessels. Lymph nodes are spherical or bean-shaped with an indented region, named hilus*,* where the lymph vessels emerge from the node. Lymphatic vessels that carry lymph from capillaries towards each lymph node is called *afferent vessel,* while *efferent vessels* come out of the lymph node bearing lymph that is

filtered and filled with lymphocytes**.** Lymph nodules present in the germinal centre of a lymph node produce lymphocytes which play great role in the immune system. Some lymph nodes are close to the skin and can be felt (palpated) with fingers, these include submandibular nodes, superficial cervical nodes, superficial inguinal nodes, and popliteal nodes. There are several *lympho centres* (about 19 in number- A *lymphocentre* represents group of lymph nodes draining similar region of the body in a particular species e.g., parotid, retropharyngeal and mandibular lymohocentres of the head region). Lymph nodes are important in clinical disease and pathology.
(**4) *Lymphatic tissue*-** these are organs that contain lymphoid tissue and help remarkably in function of the immune system. They include spleen, thymus, and tonsil.

Reproductive System

The urinary and reproductive structures have common embryonic development of some structures of both organ- complexes in the intermediate mesoderm and nearby part of the coelomic epithelium. In addition, the reproductive and urinary system shares a common channel for the passing away of their final products to the exterior (vestibule in females/urethra in male/urodeum in birds) This is why they are described as urinogenital system in some textbooks by authors.

Female reproductive organs **(Figures 21 – 24)**

The female organs are made up of the two female gonads (ovaries), which make the female gametes and hormones. There are paired uterine tubes (oviduct or Fallopian tubes) that capture ova (*ovum*-singular) from ovaries after release and carry them to the uterus-compartment for fertilization and maintenance of pregnancy after fertilization. Structurally, ovaries are paired glands located in lumbar area of abdominal cavity and placed it is very close to the kidneys. Ovarian follicles forms inside the parenchyma of the ovary and each follicle have an ovum. Several stages of development are seen in ovarian follicles (primordial, primary, secondary, tertiary, and Graafian

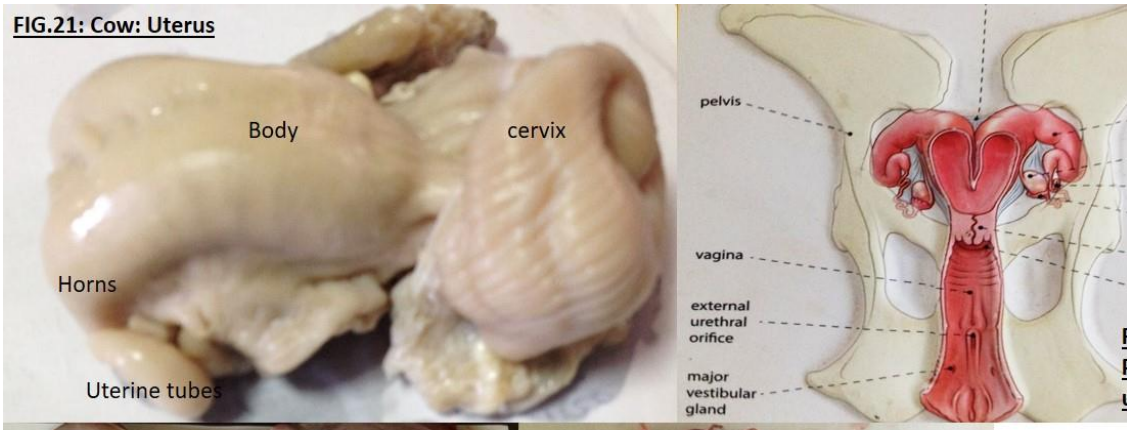
follicle). There is also the uterus, in which the fertilized ova are housed and nourished (nursed) until prenatal development is completed. The uterus of the domestic animals has a body, a cervix and two horns. Ligaments of the uterus include the *intercornual ligament* and *broad ligament* (made up of mesovarium, mesosalpinx and mesometrium). The next compartment is the vagina, which functions both as copulatory chamber and birth canal. The vestibule is the larger extension of the vagina, and it opens externally at the vulva; it is involved in the passage of urine. In the sow and cow, the vuiva has a *suburethral diverticulum,* which is a small blind sac ventral to the orifice of the urethra. The following important structures are specifically covered-ovaries, uterine tubes, uterus, vagina, vestibule and vulva, adnexa (broad ligaments and attachments carrying blood vessels, mesovarium, ovarian bursa, proper ligament of ovary, round ligament of uterus etc). The age and functional (cyclic) alterations in the female tract are discussed under physiology. *Placenta* and *placentation* are explained in embryology section. Several infectious diseases, non-infectious diseases and physical conditions affect the reproductive organs of male and female.

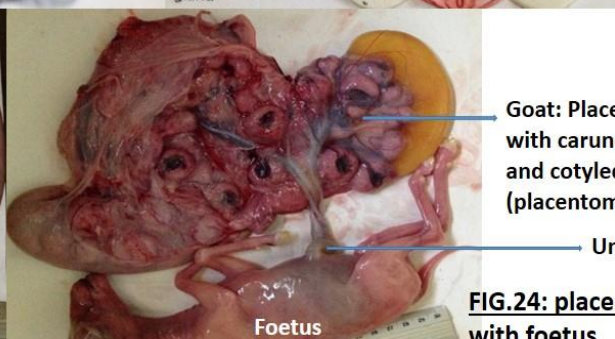
Uterine and cervical species differences: Uterus; Type:

(a) Duplex – it is seen in the opossum, mouse, rabbit-two cervixes, no uterine body, one or two vaginas (b) Bicornuate – present in cow, ewe, mare, sow, bitch, queen- one cervix, uterine body, poor to good development of uterine horns, one vagina (c) Simplex - primate -one cervix, uterine body, no uterine horns, one vagina.

In some textbooks, the uterus is rendered as being bipartite in cow, ewe, and mare and bicornuate in sow. The internal lining of uterus (endometrium) has caruncles ruminants (cow, ewe and does), but show slight longitudinal folds in sow and remarkable longitudinal folds in the mare.

Cervix – In the cow, ewe - the cervix has annular rings; ewe has more obstacles; Mare - longitudinal folds; Sow - interdigitating prominences and no fornix. Physiologically important reproductive parameters are always mentioned in relation to all domestic species and has relevance in the clinics. These parameters include time of onset of puberty, cycle length, duration of oestrus, ovulation length and gestation (duration of pregnancy). These parameters can help to evaluate the specific differences in the female reproductive structures amongst the domestic mammals and pregnancy diagnosis.





Male reproductive organs **(Figure 25)**

The male reproductive organs are made up of double gonads, testes which manufacture the male gametes and hormones; two gonadal duct systems, each is made up of epididymis and deferent ducts (which convey the exocrine product of testes to the urethra). There are accessory sex glands that make the bulk of the semen; male urethra, that extends from bladder to the unattached extremity of penis and plays a role in passage of urine out and semen into the reproductive tract of the female. The integumentary adaptations (derived from skin) include prepuce and scrotum, and they are formed in relation to the testes and penis (embryology). The scrotum is the sac that houses the testicles and spermatic cord after *descent of testes*. It is found in the inguinal region in horse and dog but placed below the inguinal region in ruminants. It is perineal in pigs and located below the anus (subanal) in cats. The male organs are discussed in the class under the following: (1) testes and adnexa (associated structures): testes, epididymis, deferent duct, vaginal tunic and spermatic cord and scrotum. The testicular function in relation to spermatogenesis is discussed. The *pampiniform plexus* and other structures assist in maintaining internal testicular temperature (2) Pelvic reproductive organs- they include: male urethra, accessory reproductive organs (*prostate* present in all domestic animals, *vesicular glands*-absent in dog and cat, *ampullary glands*-not in boar, *bulbourethral glands*-except dog and vestigial in cat) (3) Penis and prepuce-there are species variations (4) Sperm movement in the male tract and mechanism of erection of the penis-sperm is produced in the testis and flows through the coiled seminiferous tubules into straight seminiferous tubules, efferent ducts, epididymis, deferent duct and into the pelvic urethra. The spermatic cord is encased by the vaginal process and is composed of deferent duct, testicular vessels, and nerves and serous membranes. There are species differences in penis (types) and accessory sex glands*: Musculocavernous penis* –here the musculo-cavernous erectile tissues have large blood spaces which become filled with blood during erection e.g horse and dog. *Fibroelastic penis* – in this type, the predominant fibrous tissue elongates during erection by straightening of the sigmoid flexure e.g swine and ruminants, but the boar has a cock-screw shaped penis. Also, the bull,

stallion, ram, and buck have all the accessory sex glands the boar has no ampulla. In addition, in carnivores the corpus cavernous (part of erectile tissue) is changed into a splanchnic bone called *os penis*, the glans penis is poorly developed in pig, and substantial in ruminants, but highly formed (large and mushroom-shaped) in the horse. The penis of the cat is pointed caudo-ventrally from the ischiatic arch. There are important muscles associated with the penis such as: bulbospongiosus (a thick extrapelvic extension of the urethralis), paired ischiocavernosi (arise from the ischial arch), retractor penis (paired and arise from the caudal vertebrae and is made up of smooth muscles elements).

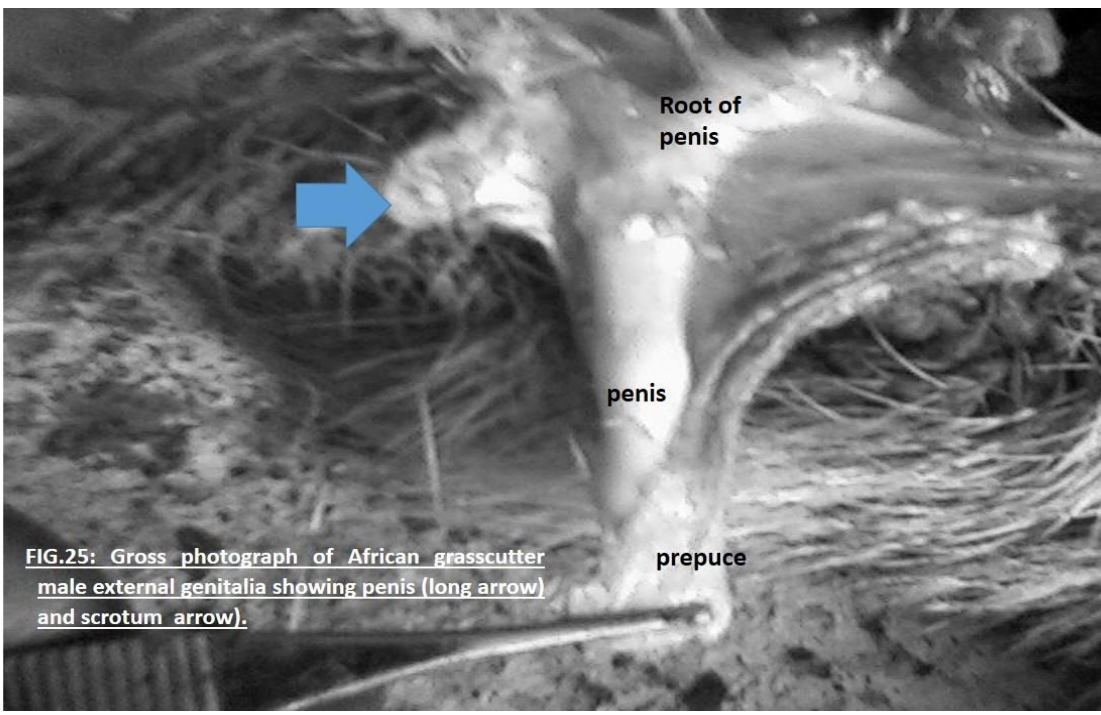


FIG.25: Gross photograph of African grasscutter male external genitalia showing penis (long arrow) and scrotum arrow).

Summary

This chapter has concisely explained the terminologies and their usage in the study of Gross Veterinary Anatomy 1 (VAN 201) with obvious applications in broader Clinical Veterinary Medicine, Surgery and Pathology. It discussed the basic systems and organs of the body that can be mainly visualised grossly (aid of the eyes), so that students can distinguish them in the abnormal (pathological) conditions at the paraclinical phase of the DVM program. Biological systems such as the skeletal and muscular systems provide locomotion for the domestic animals. Other system-organs discussed in this chapter such as digestive, respiratory, cardiovascular, and reproductive and lymphatic systems allow the appreciation of the normal function of domestic animal species in the environment. We do hope that the readers, students, and researchers will appreciate this concise text. However, sections such as integumentary system, nervous system, urinary, endocrine, and special sense organs are covered in the next phase.

Exercise

(1) Students should demonstrate the transverse and longitudinal sections, and various virtual body planes in a standing (life) goat (*quadruped*) and compare to a standing human being *(biped*).
(2) Different planes and sections could be demonstrated with an orange or solid organ like the spleen.
(3) Identify all salient features in the humerus and compare to the femur in the dog
(4) Identify the points of attachments of muscles and ligaments in the femur, tibia and fibula
(5) Describe a typical synovial joint with an illustration.
(6) List the joints in the axial and appendicular skeleton of a goat in a sequential (orderly) fashion as they occur.
(7) Name the muscles of respiration and their innervations in the goat.
(8) List the hypaxial and epaxial muscles and their functions in the domestic animal.

(9) Write a short note on the bronchial tree, lobation, lobulation and surfaces of the lung in the goat.
(10) Trace the pathways for conduction of inspired air until it is absorbed into the pulmonary vessels of the lungs in any domestic animal.
(11) Give an anatomical account of the stomach in the goat and compare the lobation and lobulation of the liver in goat, horse and dog.
(12) List 10 internal structures of the heart in goat and trace the branches of the caudal vena cava into the heart
(13) List the clinical important lymph nodes in the ox and write a short note on the lymphocentres of the axillary region in the goat.
(14) Comment on the excurrent ducts system in the goat and dog. What is spermatic cord?

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Chapter 2

VAN 202: Gross Veterinary Anatomy II (Regional Anatomy of Head, Neck and Neuroanatomy)

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Overview

The face of teaching of Veterinary Medicine is evolving globally particularly at the preclinical phase. This is due to the growing field of biomedical science and research with its multidisciplinary and interdisciplinary nature, and the emergence of new tools for disease diagnosis. The preclinical phase of veterinary medicine programme thus must be taught with a holistic view of science in mind and the future clinical relevance of basic structures and function. Gross Anatomy-II involves the head and neck region with the sense of vision, audition, taste, olfaction, and the sense organ of the brain having their anatomical basis in the head which constitute in most cases less that 5 percent of the weight of the whole body. Intricate, delicate, and strategic structures that govern the wellbeing of the animal are thus densely packed in such a limited space. In giving a good basic understanding on the structures of the head and neck to students, a large number of pictorial details have been deployed, to the end that they have a template to build upon in their continuous studies.

Objectives

The objectives of this course are:

1. identify each bone of the skull;
2. describe the basic muscles in the head and neck region and their functions;
3. explain the circulatory and peripheral nervous system as it relates to the head and neck region;
4. describe the functional soft tissues of eye, ear, tongue, nares and dentition, and the lymph nodes in the region;
5. have an overview of the brain and the spinal cord and describe the structures of the brain to embryological origin; and
6. discuss salient structures of the brain from the perspective of multidisciplinary importance.

Osteology of the Head and Neck (See Figs 1-6)

The skeleton of the head is made up of mainly the skull, the mandible, the hyoid apparatus, the middle ear ossicles, and cartilages of the external ear, larynx, and nose.

The skull is made up of the cranial and facial bones. The unpaired cranial bones are **occipital** (lateral, squamous and basilar parts that form the boundaries of the foramen magnum). The **interparietal** is centrally placed between the squamous occipital (caudally) and the parietal that flanks it laterally. It fuses with these two in adult life except horse and cats. The **sphenoid** consists of presphenoid rostrally and basisphenoid caudally while the **ethmoid** consists of the cribriform plate, the perpendicular plate, and the ethmoidal labyrinth or lateral masses. The perpendicular plate of the ethmoid divides it into two tubes and projects into the cranial cavity as crista galli or ethmoid crest.

The paired cranial bones are **temporal** (squamous, petrous part and tympanic parts). The tympanic part bears a bulbous enlargement, the tympanic bulla that is related to the basilar part of occipital bone.The **parieta**l bone forms the caudo-lateral part of the cranium. In bovine

1/3 of the parietal bone forms the roof of the cranium. The frontal bone consist of paired irregularly quadrilateral bones situated at the roof of the cranium. It consists of 4 parts; (i) squamous, (ii) nasal, (iii) orbital, and (iv) temporal. In ruminants, it caries the cornual process which support the horn.

The facial bones include the **maxilla** which is a teeth bearing bone. The lateral surface bears the infraorbital canal in which many vessels pass through. The **lacrimal** is located at the rostral part of the orbit. It also bears a deep fossa carrying the lacrimal foramen at its orbital margin. The **incisive bone/premaxilla** consists of a body, an alveolar, nasal and palatine processes. The incisive bone forms the rostral part of the upper jaw and articulates with the nasal, vomer and maxilla. It carries the incisor teeth. The **vomer** attaches to the median nasal crest in the nasal cavity from where it extends to the choanal region. It is bounded caudally with the sphenoid and cranially with the incisive, and forms the ventral part of the nasal septum. The **mandible** is the jaw bone and the largest bone of the face and carries the lower teeth. It has two rami and a body. The **pterigoid** is a thin bony plate and bounded by sphenoid caudally, palatine cranially, and vomer medially. The ventral extremity forms a small hook-shaped process called the pterigoid hamulus. The **palatine** bone is located between the maxilla and pterigoid bones. The palatine is divided into horizontal and perpendicular plates. The **malar/zygomatic bone** is bounded by lacrimal dorsally, maxilla rostrally and maxilla ventrally. It has 3 surfaces (orbital, nasal and facial/lateral surfaces) and a process (the temporal process). The facial surface is much wider and presents a smooth slightly convex surface which bears a facial tuberosity/crest at its ventral part continuous rostrally and caudally to maxilla and temporal respectively. The temporal process of the malar/zygomatic forms the zygomatic arch. The **turbinates** are scroll-like bones that projects into the nasal cavities/ nasal concha. They include the dorsal, middle, ventral and ethmoidal concha. The **hyoid apparatus** is the internal transit structure between the head and neck and forms support for the pharyngeal structures

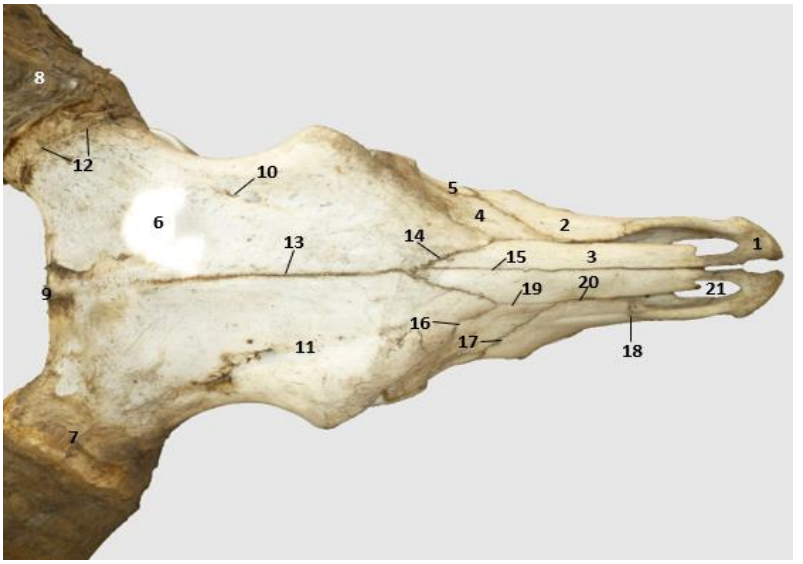

Fig.1: Bovine Skull. Dorsal surface. 1. Incisive bone 2. Maxilla 3. Nasal bone 4. Lacrimal bone 5. Zygomatic bone 6. Frontal bone 7. Cornual process 8. Horn 9. Intercornual protuberance 10. Supraorbital foramen 11. Supraorbital groove 12. Crown of cornual process 13. Interfrontal suture 14. Frontonasal suture 15. Internasal suture 16. Frontolacrimal suture 17. Lacrimomaxillary suture 18. Maxilloincisive suture 19. Nasolacrimal suture 20. Nasomaxillary suture 21. Incisive fissure

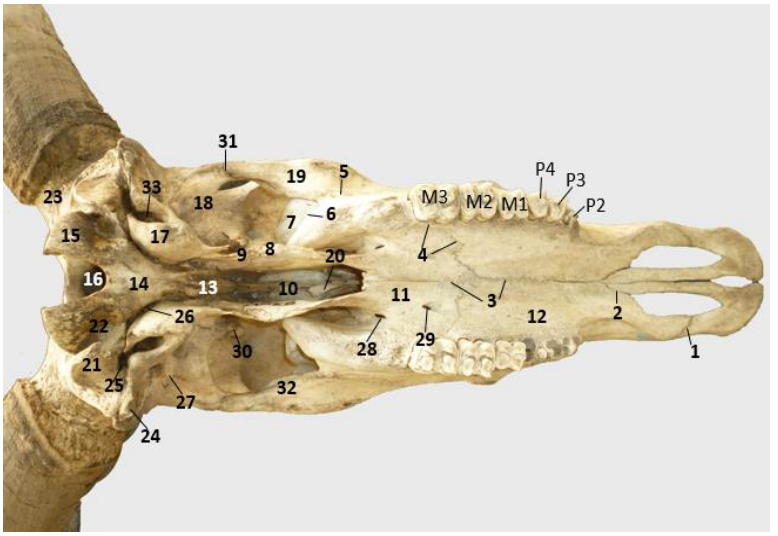

Fig.2: Bovine Skull. Ventral surface. 1., 2. Maxilloincisive sutures 3. Median palatine suture 4. Transverse palatine sutures 5. Zygomaticomaxillary suture 6. Lacrimomaxillary suture 7. Lacrimal bulla 8. Pterygoid hamulus 9. Pterygoid bone 10. Vom er 11. Palatine bone (horizontal part) 12. Maxilla (palatine process) 13. Sphenoid bone (body) 14. Occipital bone 15. Occipital condyle 16. Foramen magnum 17. Temporal bone (tympanic part) 18. Temporal bone (squamous part) 19. Zygomatic bone 20. Vomer (broken) 21. Jugular process 22. Inferior condylar fossa 23. Neck of cornual process 24. Opening of external acoustic meatus 25. Stylomastoid foramen 26. Jugular foramen 27. Retroarticular process 28. Posterior palatine foramen 29. Lesser palatine foramen 30. Pterygoid crest 31. Temporozygomatic suture 32. Zygomatic arch 33. Styloid process

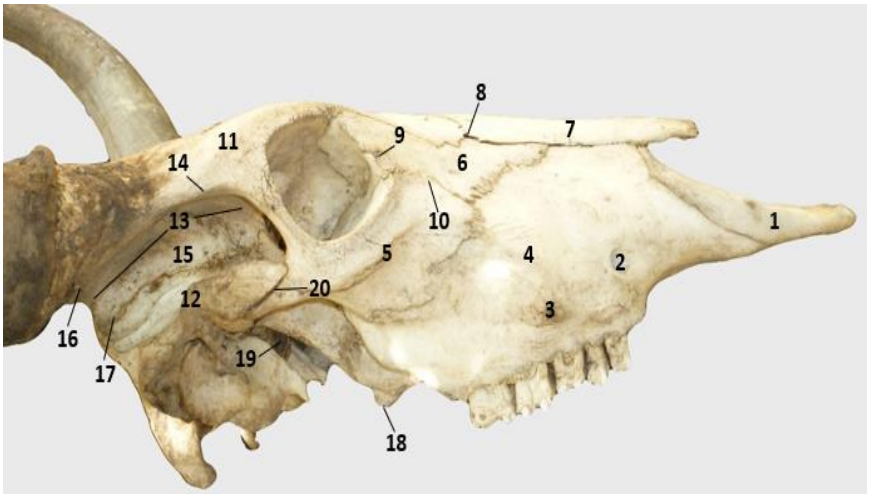

Fig. 3: Bovine Skull. Lateral surface. 1. Incisive bone 2. Infraorbital foramen 3. Facial tuberosity 4. Maxilla bone 5. Zygomatic bone 6. Lacrimal bone 7. Nasal bone 8. Nasolacrimal fissure 9. Fossa of lacrimal sac 10. Lacrimozygomatic suture 11. Frontal bone 12. Temporal bone (zygomatic process) 13. Temporal

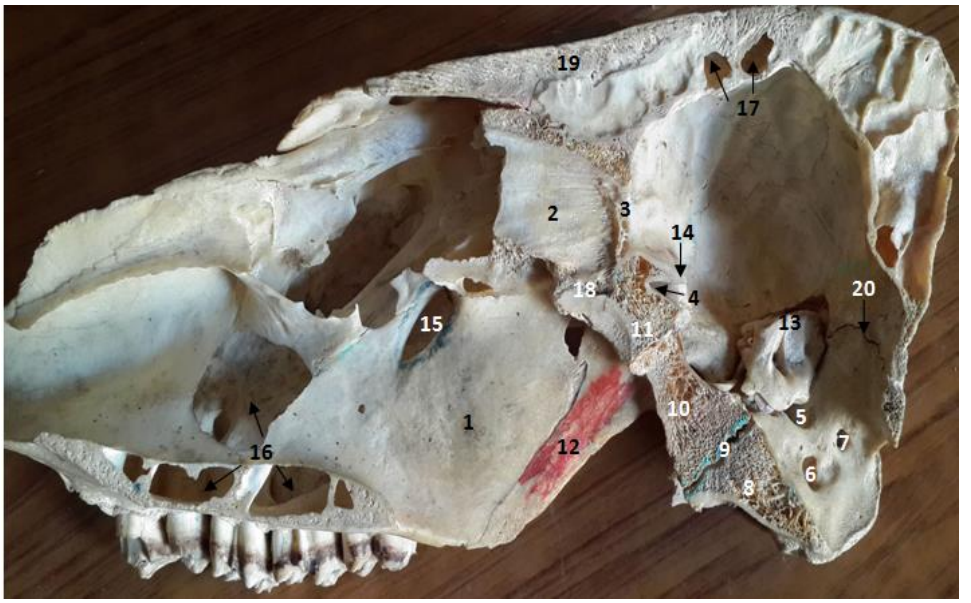

Fig. 4: Bovine skull. Median view (nasal and incisive bones removed), 1. Palatine bone (perpendicular plate) 2. Ethmoidal concha (broken) 3. Ethmoid bone 4. Optic canal 5. Jugular foramen 6. Canal of hypoglossal nerve 7. Condyloid canal 8. Occipital bone 9. Sphenooccipital suture 10. Body of sphenoid bone 11. Sphenoid bone 12. Pterygoid bone 13. Temporal bone (petrous part) 14. Optic groove 15. Sphenopalatine foramen 16. Palatine sinus 17. Frontal sinus 18. Vomer 19. Frontal bone 20. Condyloid canal (cranial orifice).

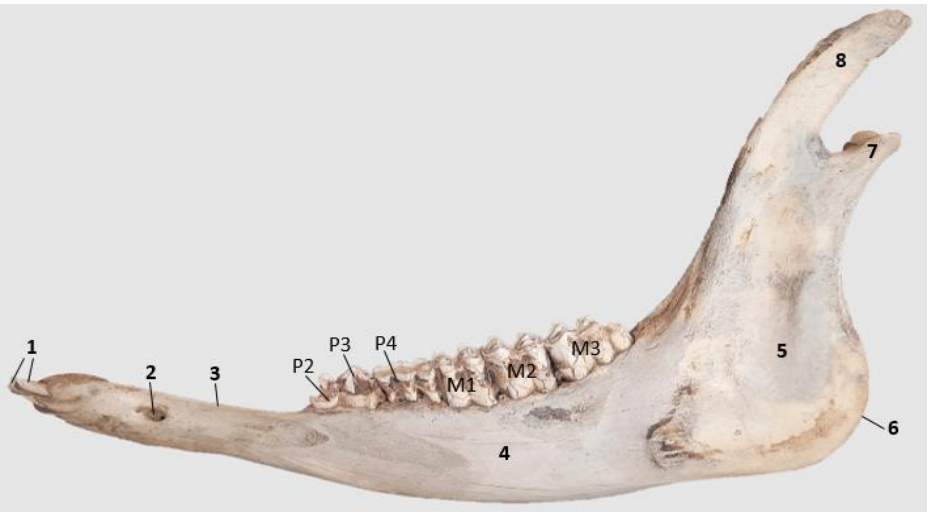

Fig.5: Bovine skull. Left hemimandible. Lateral view. 1. Incisor teeth 2. Mental foramen 3. Interalveolar margin 4. Body of mandible 5. Ramus of mandible 6. Angle of mandible 7. Condyloid process 8. Coronoid process.

2nd lower premolar tooth (P2). 3rd lower premolar tooth (P3). 4th lower premolar tooth (P4). 1st lower molar tooth (M1). 2nd lower molar tooth (M2). 3rd lower molar tooth (M3).

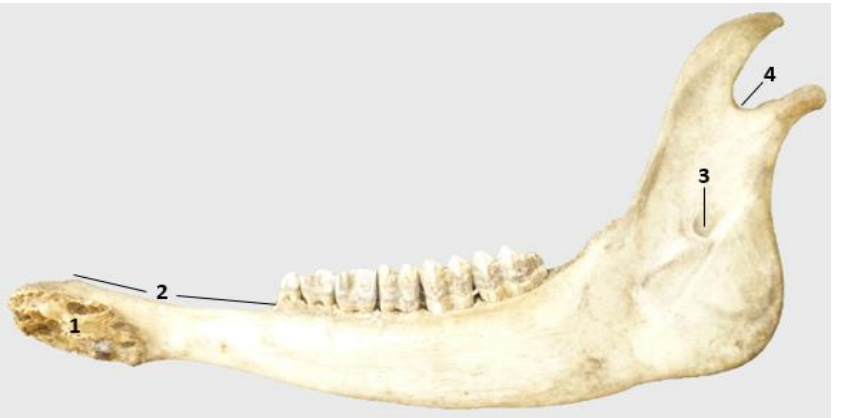

Fig.6: Bovine skull. Right hemimandible. Medial view.
1. Mandibular symphysis 2. Diastema 3. Mandibular foramen 4. Mandibular notch.

Muscles and Soft Tissues of the Head and Neck (See Figures 7-13)

Muscles of the head include (i) muscles of the eye, (ii) muscles of mastication, (iii) muscles of facial expression, (iv) muscles of pharynx and larynx (Fig 10), (vi) muscles of the tongue (Figure 10).

Muscles of the eye: The extraocular muscles of the eye comprise four rectus or straight muscles, two oblique muscles, and one retractor bulbi muscle. The straight muscles include ventral, dorsal, medial and lateral rectus muscles while the oblique muscles include the ventral and dorsal oblique muscles. The oculomotor nerve (cranial nerve (CN) III) supplies neural stimulation to the medial, dorsal, and ventral recti muscles, and the ventral oblique muscle. The dorsal oblique muscle receives neural stimulation from the trochlear nerve (CN IV) while the lateral rectus and retractor bulbi muscles are innervated by the abducens nerve (CN VI).

Muscles of facial expression: These include (i) Levator labii superioris/maxillaris (ii) Levator labii inferioris/mandibularis (iii)

Buccinator (iv) Orbicularis oris (v) Levator nasolabialis (vi) Caninus (vii) Zygomaticus. They are innervated by motor fibers in the facial nerve.

Muscles of mastication: The primary ones include the (i) Masseter, (ii) Temporalis, (iii) Diagastricus and the (iv) medial and (v) lateral pterygoid muscles.

Muscles of the neck: These muscles are made of a number of superficial muscles (platysma, sternohyoid, trapezius, omotransversarius, serratus ventralis and branchiocephalicus) and deep muscles (rhomoidus, longus colli, longus capitis, rectus capitis, scalenus, semipinalis, longissimus, splenius, omohoideus and intertransverarii. Generally, they are grouped into the (i) ventral cervical group and (ii) lateral cervical group of muscles.

Ventral cervical group: They include the (i) Cutaneous colli, (ii) Brachiocephalicus, (iii) Sternocephalicus, (iv) Sternothyrohyoideus, (v) Omohyoideus, (vi) Scalenus, (vii) Cervicalis ascendens, (viii) Rectus capitis ventralis major, (ix) Rectus capitis ventralis minor, (x) Rectus capitis lateralis, (xi) Longus colli, (xii) Intertransversales colli.

Lateral cervical group: They included: (i) Trapezius cervicalis, (ii) Rhomboideus cervicalis, (iii) Serratus cervicis, (iv) Splenius, (v) Longissimus capitis et atlantis, (vi) Multifidus, (vii) Complexus cervicis, (viii) Spinalis, (ix) Obliquus capitis anterior, (x) Obliquus capitis posterior, (xi) Rectus capitis dorsalis minor, (xii) Rectus capitis dorsalis major.

Soft Tissues of the Head

The **eyeball** (Figures 7, 11) comprises 3 tunics namely fibrous, vascular and retinal tunics. The cornea and sclera make up the fibrous tunic while the iris and ciliary apparatus make up the vascular tunic. The ciliary apparatus anchors the lens while the iris surrounds the pupil. Nerve fibers from the retina congregate at the optic disc to become the optic nerve. Blood vascular supply to the retina is by the choroidal blood vessels and the cilioretinal arteries. In primates however, a single central retinal artery in addition to the choroidal blood vessels provide blood to the retina.

The **ear** (Figure 13) comprises the outer, middle and inner ears. The pinna and external auditory canal make up the outer ear while the tympanic membrane, tympanic cavity, auditory tube and ossicles make up the middle ear. The inner ear consists of the membranous and osseous labyrinths.

There are major and minor **salivary glands**. The major salivary glands are usually larger in size, situated some distance from the oral cavity, and have long ducts. They include the parotid gland located below the ear, mandibular gland located caudal to the angle of the jaw, and sublingual gland situated under the tongue. The minor salivary glands are situated in the wall of the oropharynx and oral cavity and have very short ducts. They include labial, buccal and lingual salivary glands.

Lymph nodes of the head include the mandibular, parotid and retropharyngeal lymph
nodes.

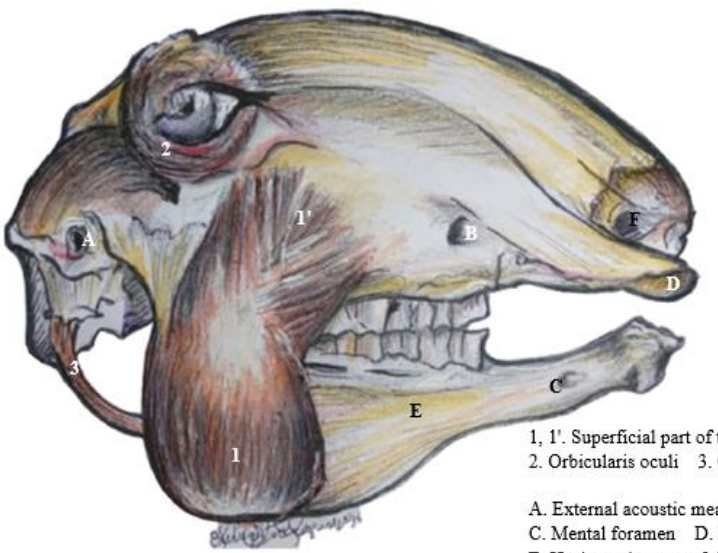

Fig. 7
Ovine. Muscles of Mastication and Other Structures. Right lateral view.

1, 1'. Superficial part of the Masseter
2. Orbicularis oculi 3. Occipitomandibular

A. External acoustic meatus B. Infraorbital foramen
C. Mental foramen D. Dental pad of the incisive bone
E. Horizontal ramus of the mandible
F. External nares

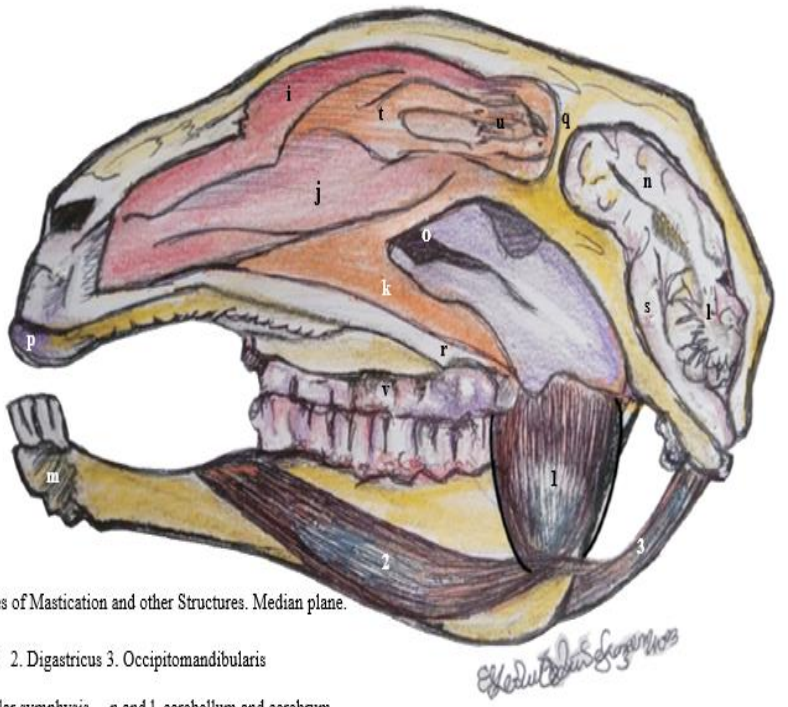

Fig. 8 Ovine. Muscles of Mastication and other Structures. Median plane.

1. Pterygoid 2. Digastricus 3. Occipitomandibularis

m. Mandibular symphysis n and l. cerebellum and cerebrum
P. Dental pad of the incisive bone q. Ethmoid bone. i. Dorsal nasal concha
o. Caudal nares (Choanae). j. Ventral nasal concha t. Middle nasal concha
u. Ethmoidal nasal concha k. Vomer r. Hamate process of pterygoid bone
s. Brain stem v. cheek teeth

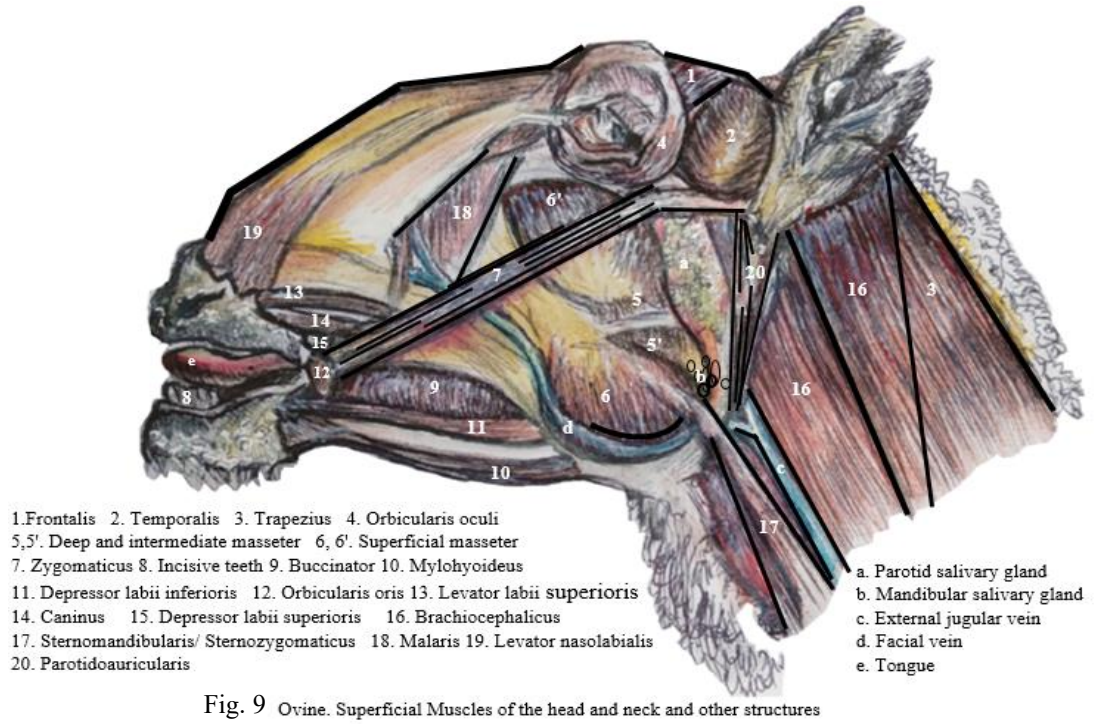

Fig. 9 Ovine. Superficial Muscles of the head and neck and other structures

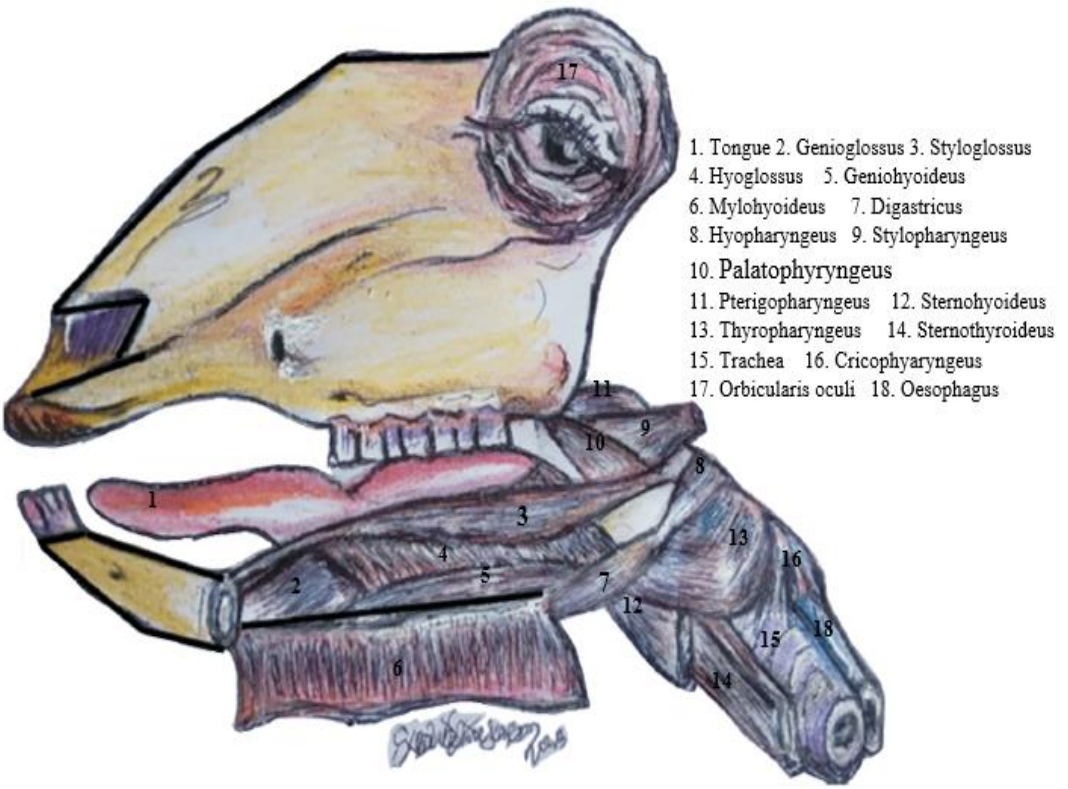

Fig. 10 Ovine. Lingual and laryngeal Muscles

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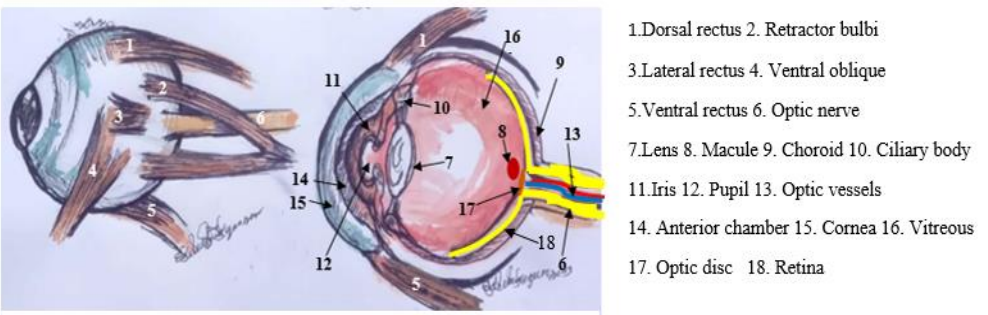


Fig. 11 Muscle of the eye. Sagittal section of the eye

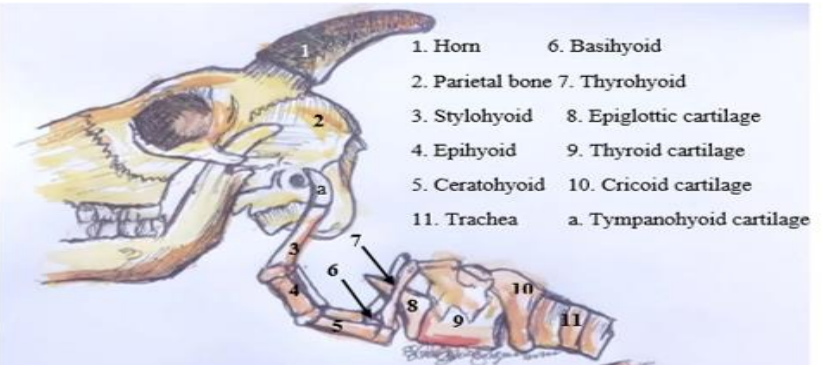
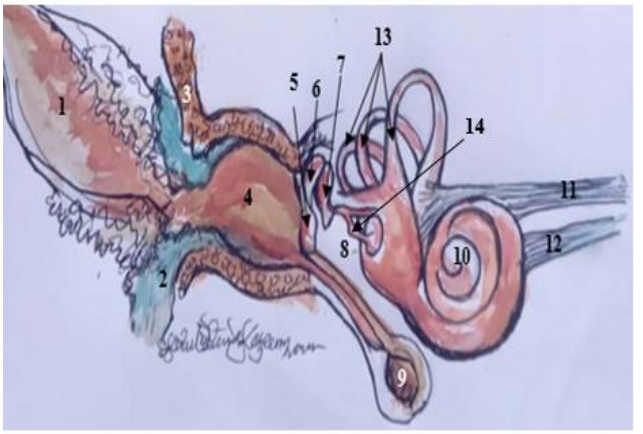


Fig. 12 The skull and Hyoid bones. Cartilages of the larynx and trachea. Ovine



1.Pinna 2. Cartilage

3. Temporal bone 4. External acoustic meatus

5. Tympanic membrane 6. Malleus

7.Incus 8. Tympanic cavity 9. Eustachian tube 10. Cochlear

11. Vestibular nerve 12. Cochlear nerve 13. Semicircular canals

14. Staples

Fig. 13 The section of the ear. Ovine

Neuroanatomy (See Figures 14-24)

Table 1. Brain Regions and Description

Primary vesicles	Brain subdivisions	Major derivatives	Associated ventricle	Associated cranial nerves
Prosencephalon	Telencephalon	Cerebrum, Olfactory bulb	Lateral ventricles	I
	Diencephalon	Epithalamus, Hypothalamus, Thalamus,	Third ventricle	II
Mesencephalon	Mesencephalon	Tegmentum, Corpora quadrigemina	Mesencephalic aqueduct	II, III, IV
Rhombencephalon	Metencephalon	Cerebellum, Pons	Rostral part of fourth ventricle	V
	Myelencephalon	Medulla Oblongata	Caudal part of fourth ventricle	VI, VII, VIII, IX, X, XI, XII

Brain meninges comprise the outer dura mater, inner pia mater, and middle arachnoid. The dura mater of the brain has an inner meningeal

layer and outer periosteal layer between which is the epidural space. Situated between the arachnoid and dura mater is the subdural space while between the pia mater and arachnoid is the subarachnoid space in which cerebrospinal fluid is found.

Commissural fibers are bundles of axons that link the left and right cerebral hemispheres. Four bundles of these fibers exist, namely, the corpus callosum and the hippocampal, posterior and anterior commissures. The corpus callosum is the largest bundle and consists of four regions namely the rostrum, genu, body, and splenium. Projection fibers are nerve fibers within a hemisphere that link the cerebral cortex with lower levels such as the diencephalon, brainstem, corpus striatum and spinal cord. These projection fibers are subdivided into afferent corticopetal fibers that transfer neural impulses to the cerebral cortex from the thalamus, and efferent corticofugal fibers that transfer neural impulses from the cerebral cortex to the spinal cord and lower centers of the brain. Association fibers are nerve fibers within a hemisphere that connect different regions of same hemisphere. These fibers are either short arcuate fibers which link adjacent gyri, or long arcuate fibers which link non-adjacent gyri. Basal ganglia are a group of brain nuclei situated deep in the white matter and associated with movement disorders. They include lenticular nucleus, caudate nucleus, substantia nigra, and subthalamic nucleus. The lenticular nucleus comprises the putamen and globus pallidus.

The spinal cord (Figure 23) is the caudal continuation of the brain situated within the vertebral canal. Parts of the spinal cord include dorsal and ventral horns, central canal, white and grey matter, ventral funiculus, lateral funiculus, dorsal funiculus, ventromedian fissure, dorsomedian sulcus, etc.

Conus medullaris refers to the conical-shaped termination of the spinal cord within the lumbar vertebrae. ***Cauda equinae*** refers to the ventral and dorsal rootlets of the spinal nerves that extend caudal to the conus medullaris. They leave the vertebral canal through the

intervertebral foramina of the sacral, lumbar and coccygeal vertebrae to form their corresponding spinal nerves.

The ***filum terminale*** is the caudal continuation of the pia mater beyond the level of the conus medullaris. The **ventricular system** of the brain and spinal cord is as described in Figure 24.

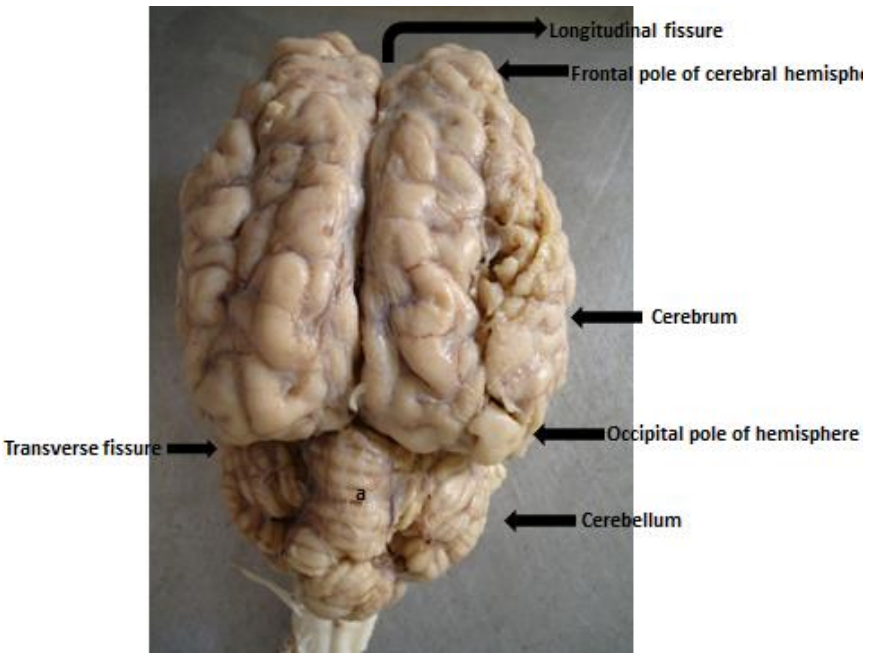


Fig 14: Dorsal view of the camel brain showing the cerebrum, cerebellum and the cerebral poles and fissures. Vermis of cerebellum (a).

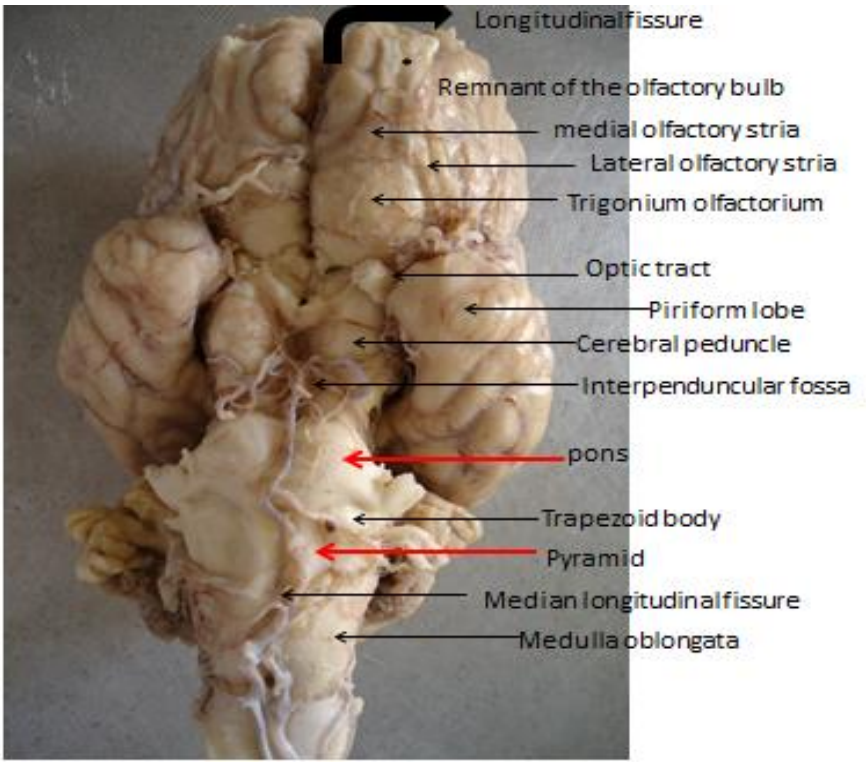


Fig 15: A light retraction on the cerebrum and cerebellum at the transverse fissure expose the hidden portions of the mesencephalon revealing the: a- rostral colliculus b- caudal colliculus c- portion of the vermis of the cerebellum c' and red arrows showing flocculus of cerebellum.

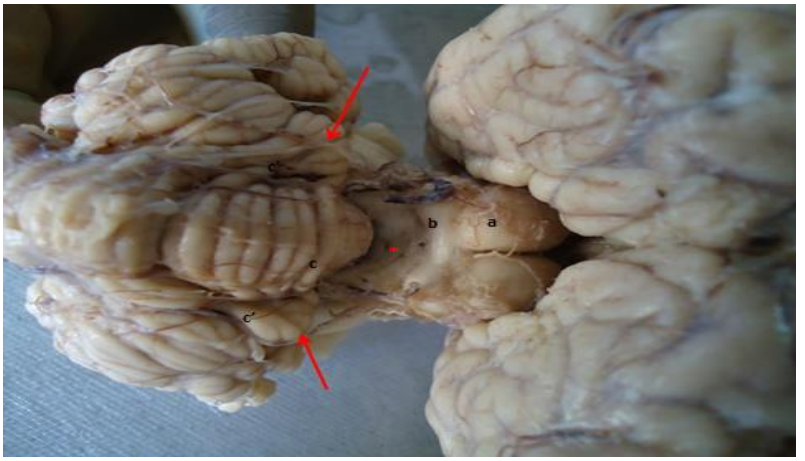


Fig 16: Ventral view of the camel brain showing Telencephalic to Myelecephalic structures.

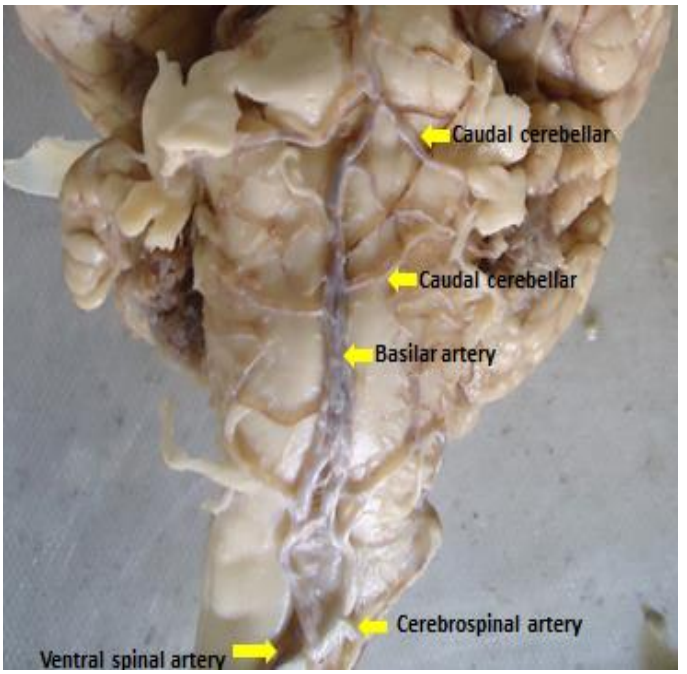


Fig 17: Ventral view of the camel brain and spinal cord showing the associated blood vessels.

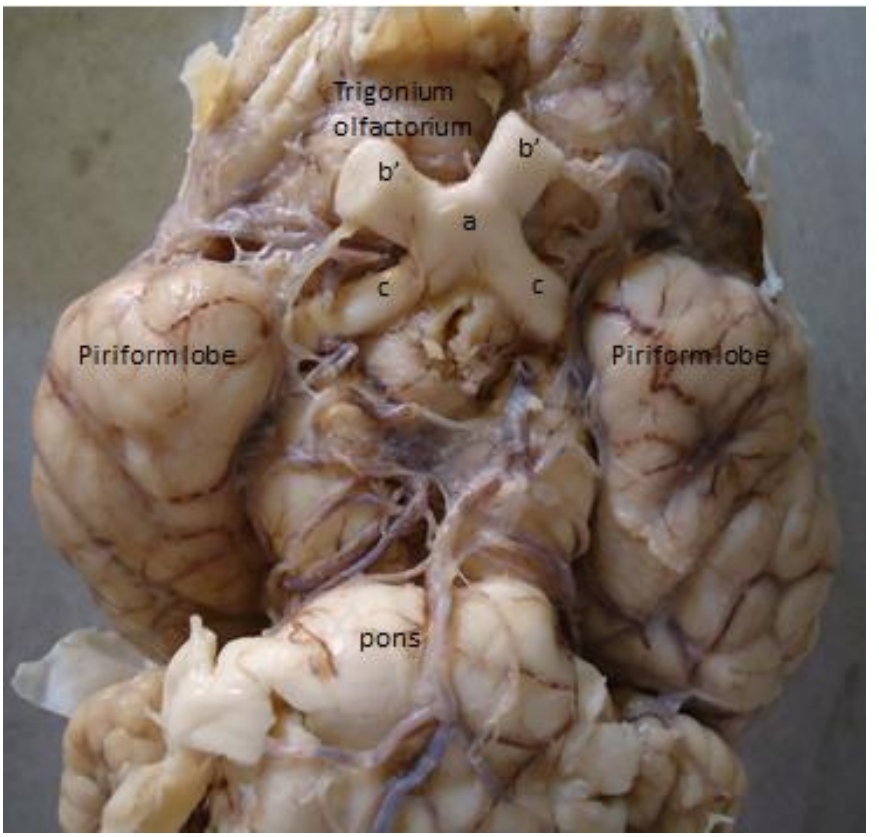


Fig 18: Ventral view of the camel brain at higher magnification showing optic chiasma (a), optic nerve (b), optic tract (c), and other parts.

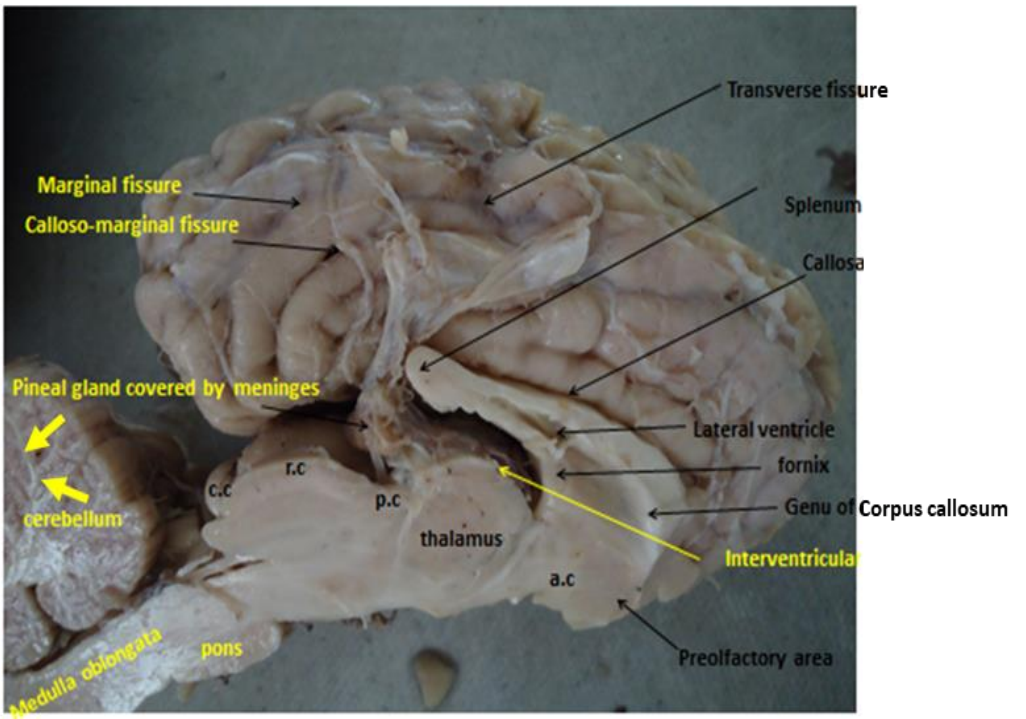


Fig 19: Mid-sagittal section of the camel brain showing the anterior/rostral commissure (a.c), posterior/caudal commissure (p.c), rostral colliculus (r.c), caudal colliculus (c.c), arbor vitae of the cerebellum (arrows), medulla oblongata and pons and other parts.

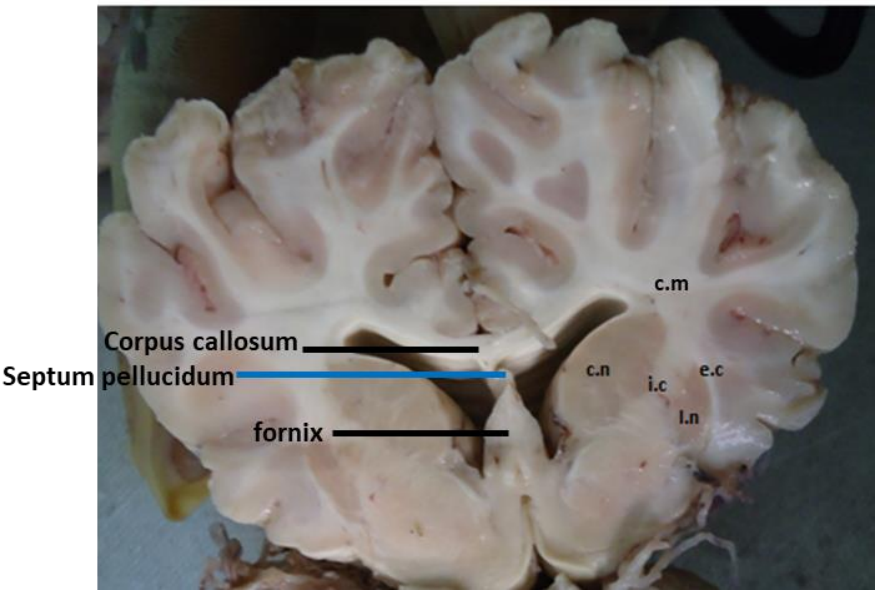


Fig 20: Coronal section of the camel brain showing the caudate nucleus (c.n), internal capsule (i.c), lenticular nucleus (l.n), external capsule (e.c) and medullary rays (c.m) and other structures.

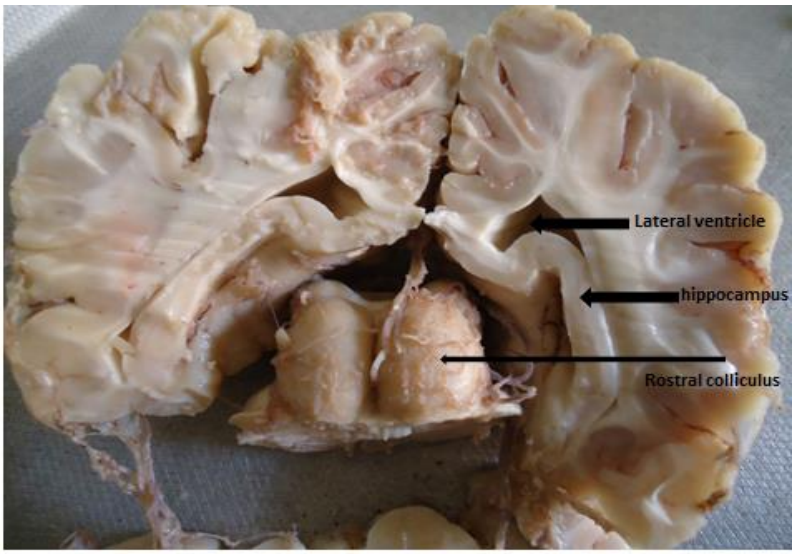
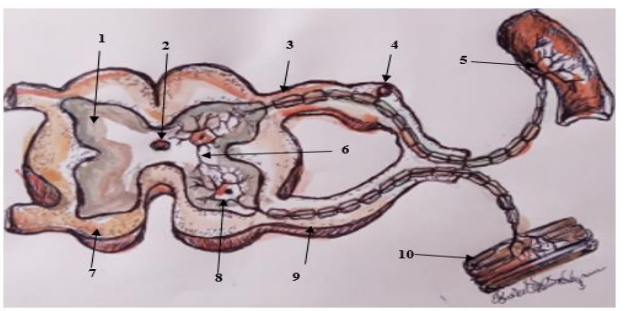


Fig 21: Coronal section of the camel brain showing hippocampus and other structures.



1. Grey matter 2. Central canal 3. Dorsal root 4. Cell body of sensory neuron 5. Receptor
6. Inter neuron 7. White matter 8. Cell body of motor neuron 9. Ventral root 10. Effector

Fig 22: Ventral view of the camel brain showing the associated blood vessels (Circle of Willis).

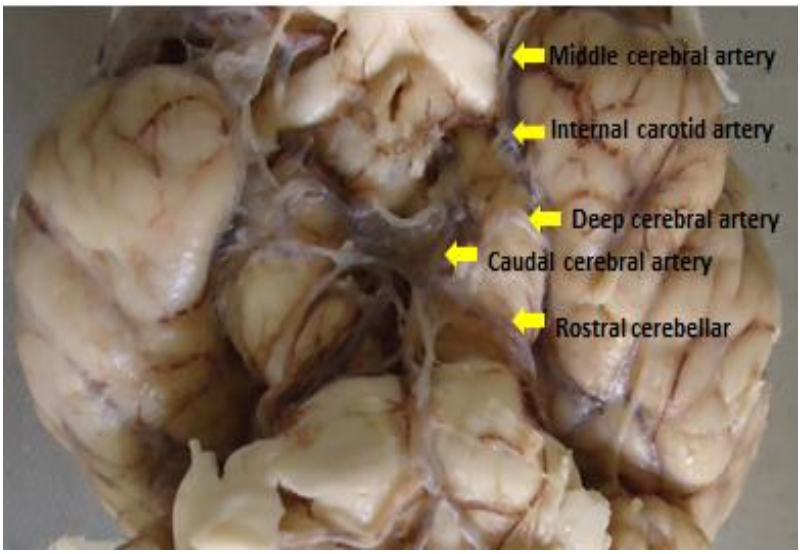
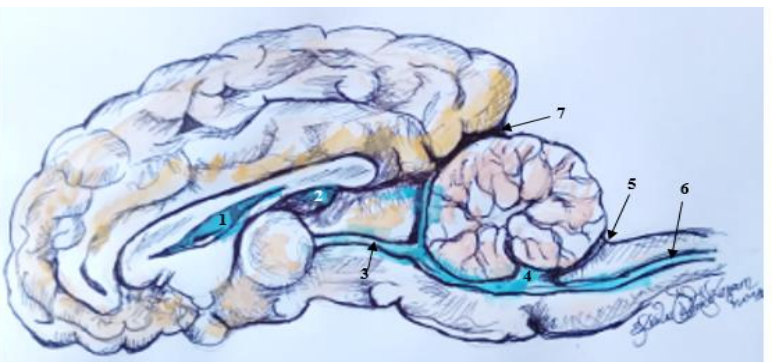


Fig 23: Showing coronal section of spinal cord and schematic of basic function.



1.Lateral ventricle 2.III ventricle 3. Aqueduct of Sylvius 4. IV ventricle 5. Cisterna magna 6. Central canal 7. Superior cistern

Fig 24: Showing ventricular system of the brain.

Summary

This chapter details the regional anatomy of the head and neck region. It lists and describes the bones of the skull, which are bones of the face and those of the cranium. The major muscles of the head are grouped into the muscles of mastication and those of facial expression. The soft structures of the head, the eyeball, ear, salivary glands are briefly described. The gross structures of the brain, the super structures of the cerebrum and cerebellum, the structures brain stem and the ventricular system of the brain are mainly described pictorially. The cranial nerves are all mentioned. The muscles of the neck are detailed with the aid of diagrams.

Exercises

1. Mention craniocaudally, bones of the ventral surface of the skull without the mandible.
2. Mention the bones of the skull that bear alveolar teeth, and the hyoid bones.
3. With the aid of diagrams, describe the eyeball, ocular muscles and related cranial nerves.
4. Mention the cranial nerves of the brain and the foramina of exit in the skull.
5. Mention the major brain structures, cranial nerves and related ventricular system to each of the five major embryonic division of the brain.

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Chapter 3

VAN 203: Veterinary Histology

Samuel Gbadebo Olukole, *University of Ibadan, Ibadan*
and **Jamiu Oyewole Omirinde,** *University of Jos, Jos*

Overview

The basic understanding of the structure of cells, tissues, organs and systems of animals form the foundation for appreciation of their functions and their relationships. The animal body is composed of different levels of organization (i.e., cell to tissue, tissue to organs, and organs to various systems of the body). There exist increasing levels of complexity in this organization with each playing vital roles in the maintenance of the physiological homeostasis of the body. The knowledge of basic tissues and their appearance under the light microscope, is therefore fundamental in the understanding of basic concepts of courses that are rendered in paraclinical and clinical phases of Veterinary programmes such as Veterinary Pathology, Medicine, Microbiology, Virology, Surgery, Radiology, Veterinary meat inspection and Theriogenology.

Objectives

The objectives of this course are to:

1. identify the components cell membrane, modifications of cell surface and cell-cell contacts;
2. demonstrate the essence of cell cycle and cell division (mitosis and meiosis);
3. demonstrate practical skills on the use of the light microscope (LM) and paraffin technique in the preparation of the histological sections;
4. identify major organelles as seen under the Transmission Electron Microscope (TEM);

5. identify the structure and components of the four basic tissues: epithelium, connective, muscle and nervous tissues;
6. identify different tissues and organ under the light microscope; and
7. Identify histological uniqueness of some organs across species.

Histology

Histology is basically the study ("*logos*") of tissues ("*Histos"*) including their structural build up as it relates to cells, tissues as well as various organs and organ systems of the body.

Microanatomy, comprise histology and cytology with the former and latter requiring the use of light and electron microscopes, respectively. The electron microscope aspect of microanatomy becomes necessary for the viewing of organelles and cellular contents that may not be obvious with the light microscope due to its magnification limitations. The appearances of these structures are complementary to the knowledge of the biomolecular blocks of tissues as well as in the comprehension of the functions of the tissues and organs of the body (physiology).

Microscopy

All objects too small for the range of the normal human eyes are viewed under the microscope. The technique of using microscopes to view objects and other associated activities that are now being achieved using a number of software are termed microscopy. The branches of microscopy include Light (optical), Electron (Transmission Electron Microscope & Scanning Electron Microscope) as well as X-ray microscopy. Light microscope could be monocular or binocular and in term of functional differences it could appear as Phase contrast microscope, the Polarizing microscope or fluorescent microscopy. Learning to use the Light Microscope (LM) is fundamental in histology. This involves knowing the basic parts of the LM and their function as

well as the magnifications of objects being viewed. LM should be properly carried with one hand on the arm and the other under its base.

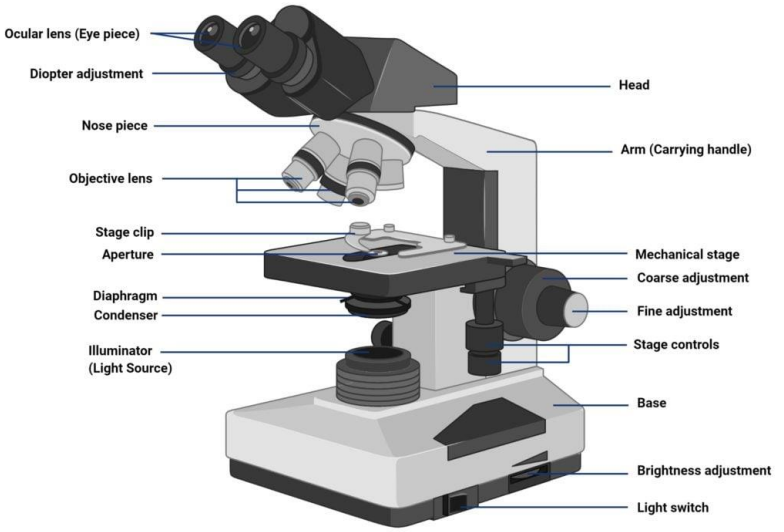

Figure 1. Diagram showing the different parts of a typical binocular microscope.

For every section placed on the stage of the microscope, the objective lens focuses the image on the condenser resulting in a clear and enlarged image whose magnification is further enhanced by the eyepiece (the point where the observer places his or her eyes when viewing the microscope). Hence, the observer sees a virtual image, an enlarged, clear image of the specimen. It is important that students get familiar with the sizes of the eyepiece as well as the objectives present on each microscope. This knowledge is required in getting the exact magnification of the specimen under examination. One of the early, basic and important tasks during histology practical is putting down the right magnification by every sketch made.

Magnification is a function of the objective lens multiplied by the eyepiece. For example, when a student is viewing a specimen using a x4 objective lens with an eyepiece of x10, the magnification of the specimen is x40 and should be written by the bottom right hand of the sketch. When using the LM, specimens are to be viewed starting from the lowest objective lens to the highest, say, 4, 10, 25, 40 and then 100. Hence, for such light microscopes, the magnifications possible would be x40, x100, 250, x400 and x1000. The x1000 magnification is only achieved by use of oil immersion and requires a certain level of confidence and expertise which a learner may not be able to handle without breaking the slides on the stage. Usually sketches expected of students during histology practical should follow the order: x10, x100, x250 and then x400, x1000 is usually demonstrated by a trained hand during student practical sessions.

Units of Measurement in Histology

Standard units of measurement are used in microanatomy: the Angstrom (A^0), that is, 10^{-10} meter; Nanometer (nm): 10^{-9} meter and micrometer (µm): 10^{-6} meter.

Paraffin Technique

Routine histological technique is otherwise known as Paraffin Technique. It employs the use of basic (Haematoxylin) and acidic (Eosin) stains.

Procedures involved in Paraffin Technique

I. Collection of Tissue
II. Tissue fixation
III. Tissue dehydration
IV. Clearing of tissue
V. Embedding of tissue
VI. Tissue sectioning
VII. Staining and mounting on slides

Fixatives used in Histology

Tissues harvested for the purpose of microscopy, whether for LM or EM are placed in a medium (fluid) known as fixative to harden such tissues. The choice of fixative should be guarded by both the type of microscopy to be carried out as well as the tissue type. Fixatives used in histology include: 4% solution of buffered formaldehyde, Potassium dichromate, Acetic acid, Picric acid, Osmic acid, Glutaraldehyde, Ethanol, Bouin's fluid, OsO_4 (Osmium tetraoxide). Neutral buffered formalin (NBF) has been demonstrated to give great results when blocks of paraffin techniques are required for more advanced techniques like immunohistochemistry. It should be noted that Glutaraldehyde, OsO_4 (Osmium tetraoxide) as well as Toludine Blue are employed in EM slide preparation, but it is imperative that the protocol being adopted in each laboratory in this regard be adhered to in choosing a fixative.

Embedding Materials/Stains and staining: Paraffin wax is the most common traditional embedding material used in histology. Nevertheless, there are several other materials used in this regard, these include Polyester wax, Nitrocellulose, Synthetic resins and freezing. Routine histology makes use of the mixture of Haematxylin and Eosin (H&E) to demonstrate tissue constituents. Haematxylin imparts a blue-to-purple colour to the tissue constituents and it is thus, a basic dye. Eosin, an acidic dye, imparts a pink-to-red colour to the tissue constituents. There a number of special stains used in histology to demonstrate different tissue constituents. These include, among others, Periodic Acid Schiff (PAS): glycogen, mucin, mucoprotein, glycoprotein; Masson's Trichrome (MT): connective tissues, capsules and lamina propria of organs; Reticulin: reticular fibres of in parenchymal organs such as liver and spleen; Verhoff's Elastic: elastic tissues: outlines of arteries, elastic lamina of arteries.

Cytology: This can be defined as the scientific study of cells of living organisms. The minute body of protoplasm surrounded by a distinct membrane with a nucleus usually centrally placed in most cases, is known as a cell. Cells can be divided into two major compartments:

cytoplasm and **nucleus**. The term **protoplasm** encompasses both compartments.

Protoplasm: This is the general term used to describe the stuff of which cells are made. Certain properties attributed to protoplasm are properties that characterize living material. These properties are irritability, conductivity, contractility, absorption and assimilation, secretion, excretion, respiration, growth and reproduction. Traditionally, the structural components of the cytoplasm are either **organelles** or **inclusions**. **Organelles** or the **"little organs"** of the cell have distinct structure and perform specific energy-requiring activities within the cell. **Inclusions** are storage components of the cell such as **pigment granules, secretory granules, glycogen and lipid.** The portion of the cytoplasm that surrounds the organelles and inclusions is referred to as the **cytosol**, the **cytoplasmic ground substance** or th**e cytoplasmic matrix. Membranous (membrane-bound) organelles** are the rough endoplasmic reticulum (rER), golgi apparatus, mitochondria, lysosomes, endosomes, and peroxisomes (microbodies). The **non-membranous organelles are** microtubules, filaments, centrioles, and ribosomes.

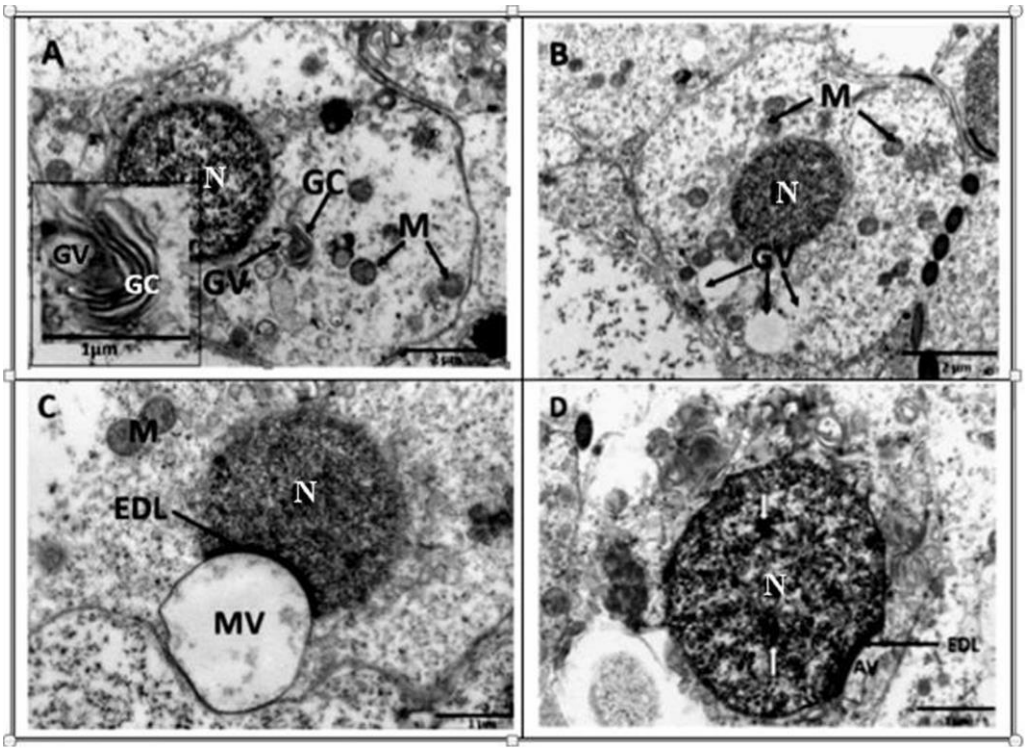

Figure 2. Demonstration of organelles. EM photomicrograph of round spermatids in the testis of African sideneck turtle. A. Golgi complex (GC) bearing budding vesicles (GV); N is the nucleus while M is mitochondria. Inset: A section of Golgi complex bearing budding vesicle. B. Round (early) spermatid bearing Golgi vesicles (GV). Mitochondria (M) are seen widely distributed around the nucleus (N). C. A macrovesicle (MV) resulting from the coalescence of small vesicles attached to the nuclear membrane of a round spermatid. EDL, electron dense layer formed at the point of attachment between the nucleus (N) and macrovesicle. D. Round spermatid resulting from the flattening of the proacrosomal vesicle, culminating in the formation of the acrosomal vesicle (AV). Note that the electron dense layer (EDL) is intact, and nucleus (N) bears sparse areas of deep staining chromatin indicated by the white arrows.

Cell Membrane

The plasma membrane, otherwise known as cell membrane, serves to separate the living cell from its non-living environment. The cell membrane also controls traffic in and out of the cell. Like other membranes, it is **selectively permeable**, allowing some substances to cross while impeding others. Lipids and proteins are the main macromolecules present in membranes, however, there are a number of carbohydrates. Phospholipids are the most abundant lipids present in the cell membrane. These phospholipids and most other membrane constituents are **amphipathic molecules** (having both hydrophobic and hydrophilic regions). The phospholipids and proteins present in membranes make available a unique structure, known as the **fluid mosaic model**. A **membrane** is hence a fluid structure embedded with proteins as well as being attached to a double layer of phospholipids.

Types of Membrane Proteins

Adhesion proteins – hold to surface, cells
Recognition proteins – recognize "self"
Receptor proteins – receive messages
Enzymes – speed up reactions
Transport proteins- (active and passive)
active – require energy to transport
passive – no energy required for transport

Exocytosis and Endocytosis

Exocytosis (out of the cell). The fusion of a vesicle with the cell membrane, releasing its contents to the surroundings. **Endocytosis (into the cell).** It is divided into two: **phagocytosis** ("cell eating") and **pinocytosis** ("cell drinking").

Endocytosis

During endocytosis, there is a folding in of plasma membrane, giving rise to a pouch that traps molecules. This pouch continues to press

inward gradually thereby forming a closed sac that breaks loose from the plasma membrane and sinks into the cell.

Phagocytosis (Originating from Greek *-phagos,* "eating"; *kytos,* "cell"), it involves the ingestion of matter by cells known as **phagocytes**. It involves the engulfment and ingestion of foreign matters. In multicellular organisms, phagocytosis functions for the purpose of defending organisms from the activities of potentially harmful invaders. In mammals, phagocytes (known as wandering cells) are found throughout the body. Larger phagocytes (macrophages) are present in the lymph system, liver and spleen among other organs.

Pinocytosis: This is the process whereby fluid cells take in fluid**.**
During pinocytosis, fluid is ingested by cells, this is followed by the turning of a portion of the cell membrane inward resulting in a sheath that is then pinched off to finally form an internal vesicle.

Exocytosis
Exocytosis is a process that involves a reversal of endocytosis. A sac inside the cell composing proteins as well as other molecules move toward the outer edge of the cell until it makes contact with the cell membrane. The membrane of the sac fuses with the cell membrane, the contents of the sac are therefore released from the cell. A number of proteins released by mammalian cells (hormones and antibodies), leave the cells where they are produced via the process of exocytosis. There are two general pathways of Exocytosis:
Constitutive pathway: identifies a process that is continual (rather than induced). Proteins that leave the cell by this pathway are released immediately after their synthesis and exit from the Golgi apparatus (example, in the secretion of immunoglobulins by plasma cells and tropocollagen by fibroblasts).
Regulative pathway: involves proteins that are stored following synthesis in secretory granules. The name regulative indicates the regulatory event that must be activated for secretion to occur (in the release of zymogene granules by Chief cells and pancreatic acinar cells).

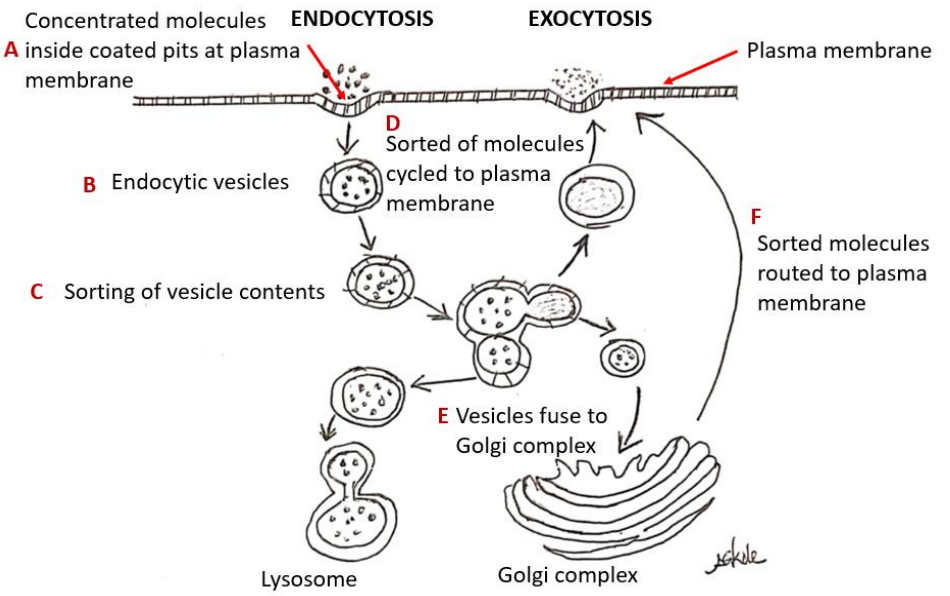

Figure 3. Illustration of Endocytosis and Exocytosis.

Junctional Complexes

The apical junctions between cells in many epithelia are equipped with microscopic ceiling and adhesive structure known as the junctional complex (JC). The JC isolates the sensitive internal environment of the organism from the noxious, toxic, and infectious external environment, for example, the noxious contents of the GIT are isolated from the sensitive gut wall by JC.

There are four major components of the Junctional complex:

I. Zonula Occludens (Tight junction)
II. Zonula Adherens (Intermediate junction)
III. Macula Adherens (Desmosome)
IV. Gap Junction (Nexus).

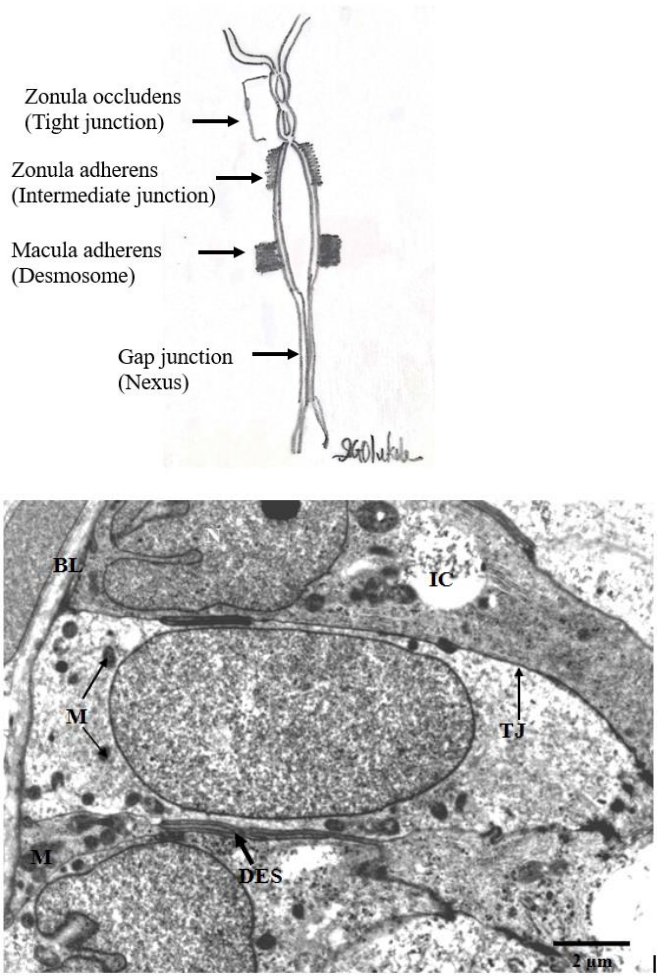

Figure 4. Left-Diagram demonstrating the junctional complexes (left). Right-Transmission Electron Microscope section of the ductuli efferentes of *P. castaneus* showing the epithelial cells with oval and irregular nuclei (N) lying over the basal lamina (BL). Notice the presence of tight junction (TJ) as well as desmosome-like cell-to-cell contact (DES), basally located mitochondria and supranuclear intercellular canaliculi (IC). (Olukole *et al*., 2018)

Cell Surface modifications

The outer surface of the plasma membrane shows some structural modifications:

Microvilli: Tiny finger-like structures on the surface of epithelial cells. They are involved in absorption and secretion. They help to increase the available surface area for absorption and secretion. A microvillus has a diameter of about 0.08 µm and are abundant in the epithelium of the **small intestine** and **kidney.**

Cilia and Flagella

Cilia and flagella are highly motile extensions of the apical surface membranes.

The major difference in cilia and flagella:

Length:Cilia (5-15 µm) shorter than flagella (150 µm)

Size: Flagella bigger.

Number present on a cell: cilia more

Pattern of beating: cilia (whip-like) and flagella (waves-like)

Cilia are found in the tracheobronchial tree, the uterus, oviduct (pushing down ovum), ventricles of the brain, rods and cones of the retina.

Stereocilia

Stereocilia are long projection of the cell membrane, similar in structure to microvilli though they are sometimes branched and are longer than the microvilli and are present on the epithelial surface of epididymis (Omirinde *et al*., 2023). Unlike the cilia, stereocilia lack motility. Stereocilia are found in the epididymis, vas deferens and inner ear.

Flagella: Flagella are found on mammalian spermatozoa.

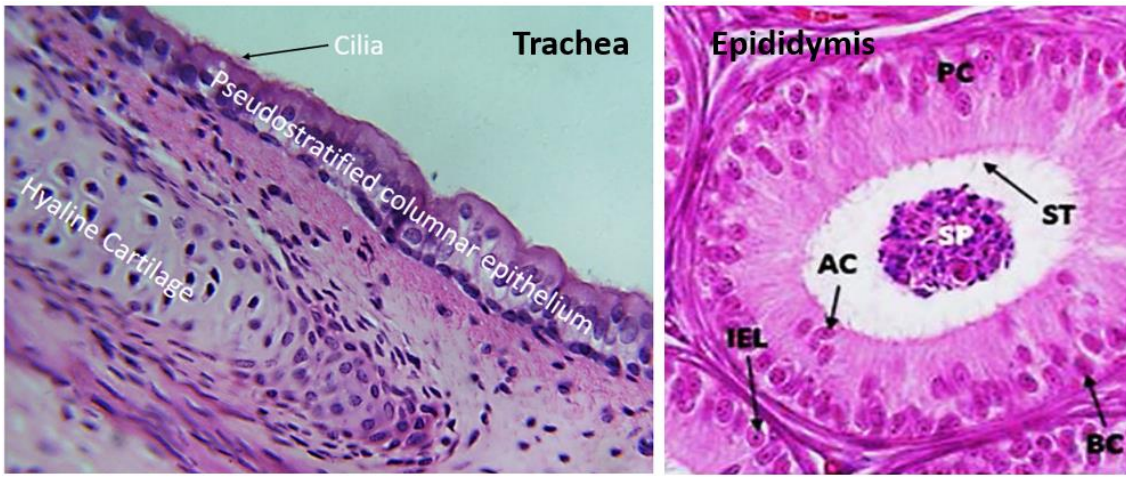

Figure 5. Illustrations of cell surface modifications.
Cilia in respiratory epithelium typical of the trachea and Stereocilia in the epididymis. (Omirinde *et al*., 2022).

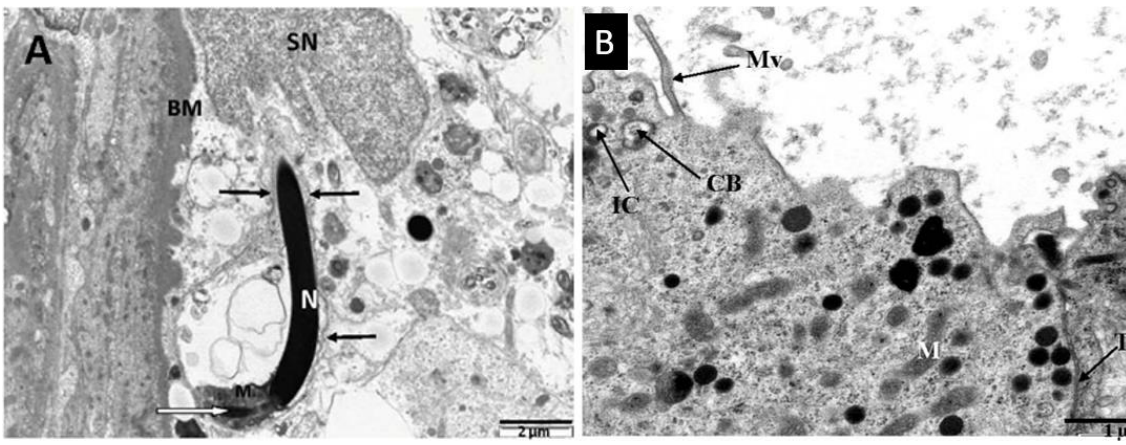

Figure 6. Illustrations of cell surface modifications
A. Flagellum. Transmission Electron Microscope section showing differentiating spermatid of *P. castaneus.*Elongating spermatid showing the emergence of the **flagellum** from distal centriole (white arrow) surrounded by mitochondria (M). The entire spermatid is surrounded

by the cytoplasmic processes of Sertoli cell. N: Nucleus of spermatid; SN: Sertoli cell nucleus; BM: basal membrane of seminiferous tubule. B. Microvillus. Transmission Electron Microscope sections of the apical portion of the rete testis. IC: Intercellular canaliculi; M: mitochondria; **Mv: microvillus**; TJ: Tight junction. (Olukole and Oke, 2020).

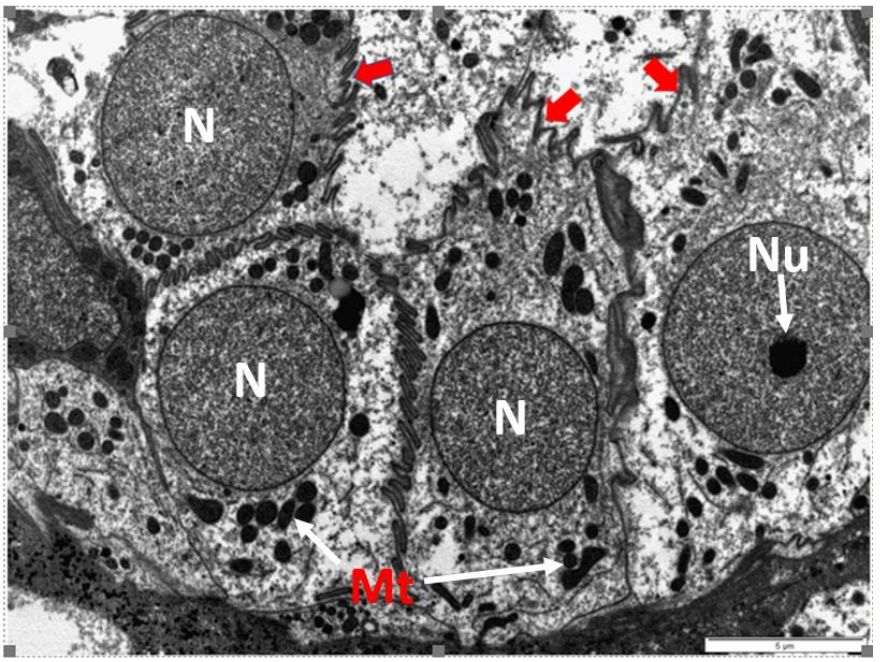

Figure 7. Illustration of cell surface modification (Apical brush borders) Transmission Electron Microscope section of the proximal convoluted tubule of the kidney of the African sideneck turtle (*P. castaneus)* showing a lumen having typical apical brush borders (Arrows); N: Nucleus, Nu: Nucleolus; Mt: Mitochondria.

Cycle and Cell Division

Cell cycle

The cycle can be divided into two principal stages – **Mitosis** and **Interphase**. **Interphase** is further divided into **S, G_1,** and **G_2 phases.** During the S phase (otherwise known as the synthesis phase), the nuclear DNA is duplicated. The first gap or **G_1** phase is the period between the M phase and the beginning of the S phase. This period follows mitotic division during when cell growth occurs. During this phase, external factors involved in the regulation of the next stage of the cell cycle are activated. The first gap is the longest phase of the cell cycle. The interval between the end of S phase and the commencement of the mitosis is known as the second gap or **G_2 phase.** This is a relatively short phase, being the period in which stem cells prepare for mitotic division. However, some terminally differentiated cells leave the cell cycle after mitotic division and enter a state of continuous differentiation activity otherwise known as the **G_0 phase**. These cells leave the cycle at the G_1 phase. Following this, the facultative dividers therefore enter the G_0 phase while retaining their potential to re-enter the cell cycle when sufficient stimulus is applied. This stimulus may be in response to injury or certain auto-immune reactions. Liver cells are facultative dividers that act as stem cells because of massive liver injury.

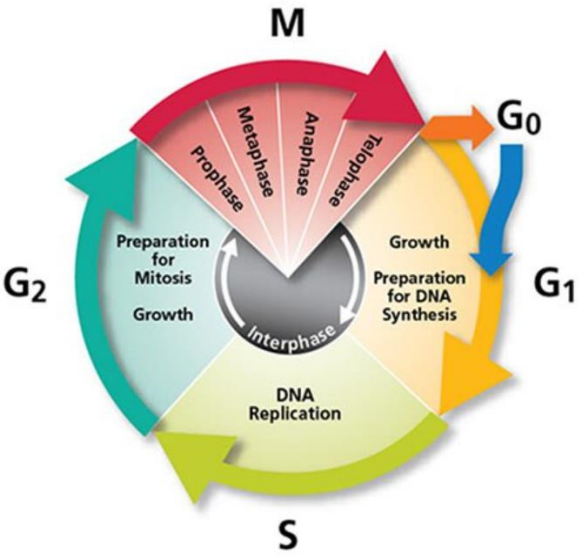

Figure 8. Diagrammatic presentation of the cell cycle

Cell division

Cells divide by two processes mitosis and meiosis, which are fundamentally different and serve different purposes. Mitosis is the process of cell division by which somatic cells divide. It ensures that each daughter cell receives a diploid, (2n), chromosomes just as the parent cell. Meiosis is the process that gives rise to gametes. It brings about reduction in the number of chromosomes from diploid (2n) to haploid (n) and allows for interchange of hereditary material between chromosomes.

Mitosis

This is a process of cell duplication, through which a cell gives rise to diploid cells, with each sharing striking genetic resemblance with the parent cell. Mitotic process is characterized by two major events; nuclear division otherwise called **karyokinesis** and cytoplasmic division **or cytokinesis**. Whenever nuclear division is not accompanied with complementary cytoplasmic division, the eventual result is a

binucleated cell formation. Four phases of mitosis are defined: prophase, metaphase, anaphase and telophase.

Prophase

At the commencement of prophase, chromosomes (earlier duplicated during the interphase period of the cell cycle) become markedly conspicuous in the nucleus. Then it increases, thickens, and is reduced while nucleoli earlier noticed becomes inconspicuous. The centrioles begin to move to the opposite ends of the cell with fibres extending from the centrioles forming mitotic spindle (interpolar microtubules). The prophase phase ends with the loss of the nuclear envelope.

Metaphase

In this phase, mitotic spindle migrates into nucleus where each replicated chromosome becomes attached, at the spot referred to as the **kinetochore**. The chromosomal entities then become arranged along the spindle equatorial plane, known as the **equatorial** or **metaphase plate**. This structural arrangement averts the formation of daughter cells with disproportionate chromosomal numbers.

Anaphase

This phase is typified by the division of centromere binding each duplicated chromosomal chromatid. The centrioles are later separated apart forcing the chromatids of each duplicated chromosome to be dragged to the opposite ends of the spindle, hence resulting in fine identically duplicated genetic material.

Telophase

During telophase, the chromosomes begin to straighten out to assume their interphase configuration. There is appearance of nuclear envelope and nucleoli become conspicuous. It is important to mention that cytokinesis process also occurs during telophase. The process is characterized by the indentation of the plasma membrane in the vicinity of the spindle equator to create a circumferential furrow around the cell, the cleavage furrow, which advanced by constricting the cell till two daughter cells with identical genetic constitution of the parent cell are cleave out.

Meiosis

This is the process in the sexual cycle that gives rise to gametes thereby reducing the chromosome number from diploid to haploid (2n to n). Important key points to note:

1. Diploid -involves a double (two) complete sets of chromosomes (2n).
2. Haploid - involves a single (one) set of chromosomes (n).
3. Homologous chromosomes: these are set of a pair alike chromosome – with each one coming from the male and female
4. Gametes – single set or haploid sex cells that fuse to form a fertilized egg.
5. Zygote - a fertilized egg.

Stages of meiosis

A. Interphase - duplication of DNA

B. **Prophase I** – With the exception of synapsis formation, this is the same as observed in mitosis.

1. Synapsis – refers to the homologous chromosomal pairing
2. There is shortening and thickening of chromatin to become chromosomes
3. Nuclear envelope becomes inconspicuous
4. Disappearance of the Nucleolus

C. **Metaphase I**

1. There is lining up of homologous chromosomes in pairs across the equator
2. Spindle fibers become attached to the chromosomal centromeres.

D. **Anaphase I** - separation of homologous chromosomes

E.**Telophase I**

1. Arrival of chromosomes at spindle poles
2. Reformation of nuclear envelope in some cells
3. The occurrence of cytokinesis divide cells into two with each cell having one homologous chromosome each.

F. **Prophase II**

1. Shortening and thickening of chromosomes
2. Disappearance of nuclear envelope
3. lack of cell duplication

G. **Metaphase II**
1. Alignment of chromosomes along the equator
2. Attachment of spindle fibers to the centromeres

H. **Anaphase II**
1. Centromeres divide
2. Separation of sister chromatids to become chromosomes.

I. **Telophase II**
1.Formation of nuclear envelope around each set of chromosomes
2. Appearance of nucleolus within each nucleus
3. lengthening of chromosomes to become indistinct.
4. Occurrence of cytokinesis to forming 4 cells.

Differences between mitosis and meiosis

		Mitosis	Meiosis
1	Purpose	Production of somatic cells	Production of germ cells
2	Process	Cell duplication (from diploid to diploid)	Cell reduction (from diploid to haploid)
3	Presence of synapsis	No	Yes (homologous chromosome pairing)
4	Number of cell divisions	One	Two
5	Final product	Two daughter cells (genetically identical to parent cells)	Four daughter cells (genetically different from parent cells)

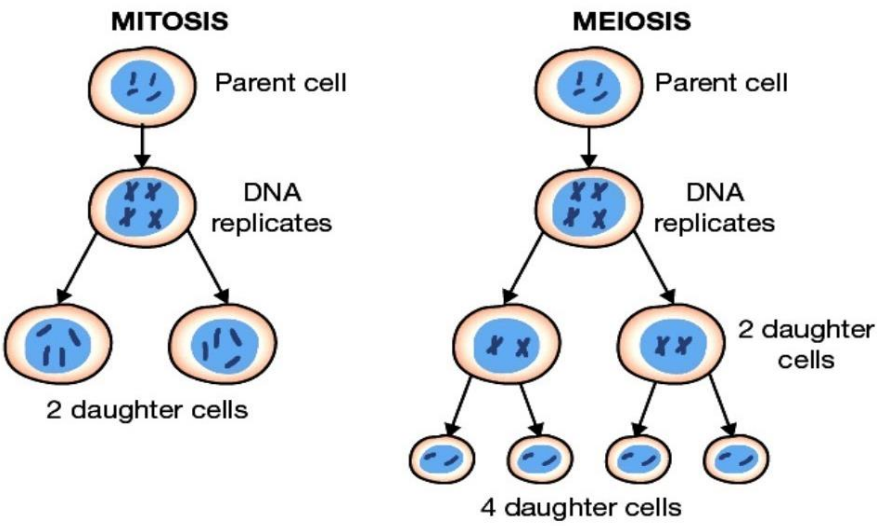

Figure 9. Diagrammatic expression of the differences between mitosis and meiosis.

Basic tissue types

There are (4) types of tissue: Epithelial, connective, muscle and nervous tissues.

Similarities among tissue types:

1. All contain cells.
2. All contain s cells that make up tissues with similar functions.
3. They all cover s and line organs/cavity walls.
4. They all form boundaries.

Special Characteristics

I. As an interface tissue.
II. Protection, absorption, filtration, secretion and excretion.
III. Exhibits polarity: Apical (superior) and basal (inferior) surfaces.
IV. Avascular, but innervated.
V. Supported by connective tissue.
VI. Cells are attached to a 'basement' membrane.

VII. Ability to regenerate.

Epithelial tissue

Each body surface is lined with or covered by an epithelium; cells connected to one another continuously. Secretory glands, inclusive of the mammary, sweat and salivary glands are derivatives of epithelium. An epithelial tissue lacks blood vessels, lies on a base, the basal lamina. Epithelial cells get nourished through the process of diffusion from blood vessels located outside the base of their respective epithelium. During embryogenic development, epithelial tissue develops from the germ layers **ectoderm** (epidermis), **mesoderm** (serous cavity inclusive of pericardium, peritoneum, and the pleura) and **endoderm** (gastro-intestinal). It is worthy to note that the lining of blood vessels otherwise known as **endothelium** derives from mesenchyme and is more grouped with the connective tissue.

Epithelial tissue classification

Epithelial tissue classification is based on two main criteria: number of layer(s) and the shape of the cells found on the basal lamina. Based on number of layer(s), an epithelium could either be **simple epithelium** (having one layer) or **stratified epithelium** (having more than one layer). Based on shape, simple epithelium can be **simple squamous (**flat); simple **cuboidal** (cube or square) or simple **columnar (**tall or thin). Epithelial cell surface may be modified, having **cilia** (ciliated cells), typical of respiratory epithelium; **microvilli** (absorptive cells found in the small intestine) otherwise known as apical **brush border**. **Stratified epithelial cells** may be **stratified squamous epithelia** (more than one layer of flat cells) found in the esophagus and epidermis of the skin; **stratified cuboidal epithelia** (more than one layer of square-like cells), being classified based on the shape of cells nearest to the base of the epithelium. The epithelium of the skin (outermost layer-epidermis) is composed of a layer of keratin and is therefore known as **keratinized** (dry) epithelium. In histological sections, some epithelia cells present a false appearance of being multilayered, especially when such cells lie on the basal lamina but reach the apical

surface or vice versa. Such epithelia cells are termed **pseudostratified**. Respiratory tract bears pseudostratified columnar epithelium with cilia and goblet cells (mucus-producing cells). In some histological sections of multilayered cells, the cells nearest to the basal lamina might be squamous followed by some layers of columnar or cuboidal cells in an orderly transition. This is known as transitional epithelium as found in the urinary bladder where it is under the influence of mechanical changes due to volume of content (Bacha and Bacha, 2000). Hence, an empty urinary bladder has thicker and more layers of epithelium than the bladder full (distended) bladder typified by the cells being thinner and less layers (that is, the epithelium appears stretched) (Bacha and Bacha, 2000).

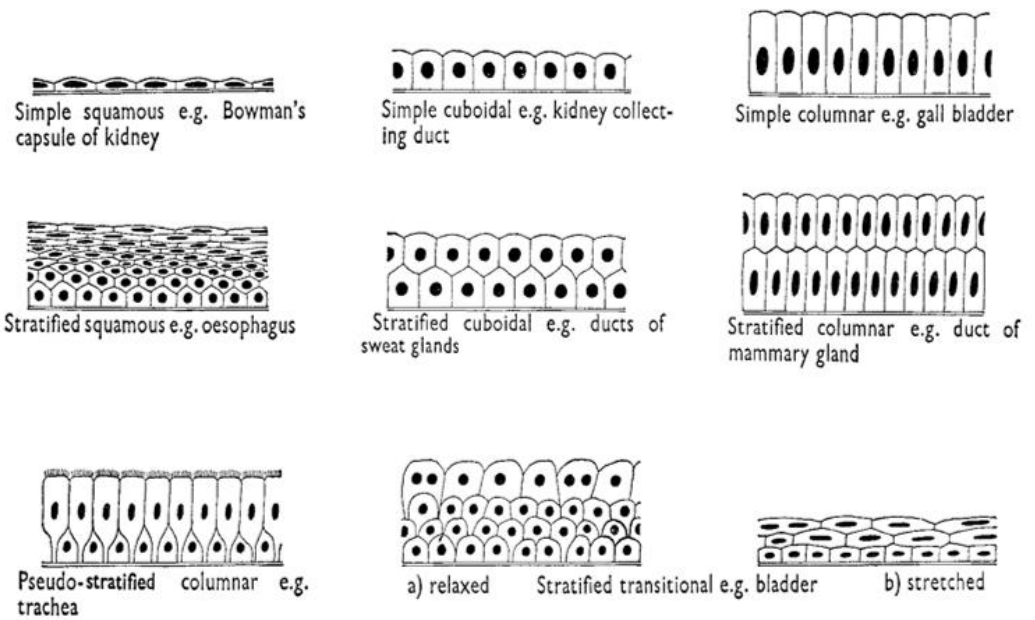

Figure 10. Diagram showing the different types of epithelia.

Glandular epithelium

One of the specialized functions of epithelia is **secretion**. **Glands** consist of groups of epithelial cells modified to synthesize and secrete. Glands are classified as:

(a) Exocrine glands, which secrete to the external environment via ducts.

(b) Endocrine glands, which secrete directly into the blood (and are also known as ductless glands)

(c) Mixed glands, which have both exocrine and endocrine secretions.

Secretion of exocrine glands is classified as:

Merocrine (or **eccrine**) **secretion**: This is the most common type of exocrine secretion. Secretory granules (packaged in the Golgi bodies) migrate to the apical surface of the cell. The membranes of the secretory granules fuse with the apical membrane and the secretions are released to the external environment by exocytosis.

Apocrine secretion: With apocrine secretion the apical portion of the cells, together with the secretory contents, budded off and released to the lumen or external environment. Examples of such apocrine secretion are found in the apocrine sweat glands of the armpits.

Holocrine secretion: Holocrine secretion involves the secretion of whole cells and their contents. This is best seen in the sebaceous glands associated with hairs of thin skin.

Connective tissue

Tissue binding other tissue or cells together are known as connective tissues (being the most diverse and abundant tissue found in the body of mammals). Originating from the mesenchyme, they provide mechanical support responsible for the maintenance of the structure and hence, function of tissues and organs.

Main classes of connective tissue are connective tissue proper, cartilage, bone tissue and blood.

Characteristics of connective tissue

I. Mesenchymal origin (mesenchyme derived from mesoderm).
II. Varying degrees of vascularity.
III. Non-living extracellular matrix, consisting of ground substance and fibres.
IV. Cells are not as abundant nor as tightly packed together as in epithelium.

Connective tissue fibres; Connective tissue fibers are composed of structural proteins. The three main types of fibers are:
Collagen fibres: These are the most abundant proteins in the body (up to 30% dry weight). Collagen is synthesized by a wide number of cell types (including fibroblasts, osteoblasts, chondroblasts, odontoblasts, reticular cells, epithelial cells, endothelial cells, smooth muscle cells, Schwann cells).

Reticular fibres: Reticular fibers are very thin and are not visible in normal histological preparations after regular staining (H & E), however they can be visualized like Reticulin that stain black after impregnation with silver salts.

Elastic fibres: Elastic fibres are highly elastic and stretch in response to tension. They are mostly formed from the protein **elastin.**

Classification of connective tissue: The two main categories of connective tissue are: Dense and Loose connective tissues.

Loose Connective Tissue: Loose connective tissue (**areolar tissue**) is the more common type. It fills the spaces between muscle fibers, surrounds blood and lymph vessels, is present in the serosal lining membranes, in the papillary layer of the dermis and in the lamina propria of the intestine respiratory tracts, among others.

Dense Connective Tissue: Dense connective tissue is also divided into two sub-categories:

Dense irregular connective tissue: Dense irregular connective tissue has bundles of collagen fibers that appear to be randomly orientated (as in the dermis).
Dense regular connective tissue: Dense regular connective tissue has closely packed densely arranged fiber bundles with clear orientation (such as in tendons) and have relatively few cells.

Cartilage

Cartilage belongs to the skeletal tissues and is a specialized form of connective tissue. Cartilage is composed of cells, **chondrocytes** (2-5% of the tissue volume only) located in **lacunae** surrounded by an intercellular **matrix**.
Cartilage is an **avascular tissue** with no blood vessels of its own, though in some cases, such as in the epipiphyses of long bones, blood vessels traverse the tissue in cartilage canals to supply nutrients to other tissues. Cartilage is a tissue of very **low metabolic activity** and cell turnover (except in the embryo). Cartilage receives its nutrients from blood vessels from a surrounding dense connective tissue, the **perichondrium**. Nutrients and metabolites pass to and from the cells via the matrix by diffusion. Nerves are not present in cartilage, but nerves and nerve ending are present in the perichondrium.

Cartilage is classified as:
(a) Hyaline cartilage
(b) Elastic cartilage
(c) Fibrocartilage

Bone

Bone tissue is a specialized form of connective tissue and is the main element of skeletal tissues. It is composed of cells and an extracellular matrix in which fibers are embedded. Bone tissue is unlike other connective tissues in that the extracellular matrix is calcified.

Functions of bone tissue

(a) The **skeleton** is built of bone tissue. Bone provides the internal support of the body and provides sites of attachment for tendons and muscles, essential for locomotion.

(b) Bone provides **protection for the vital organs** of the body: the skull protects the brain; the ribs protect the heart and lungs.

(c) The **hematopoietic bone marrow** is protected by the surrounding bony tissue.

(d) The main **store for calcium and phosphate** is in bone. Bone has several metabolic functions especially in **calcium homeostasis**.

Muscle tissue

Muscle tissue develops from embryonic mesoderm (except for myoepithelium) and is characterized by its well-developed properties of contraction. It is responsible for the movements of the various parts of the body.

Muscle is classified into 3 categories according to morphology and physiological function: They include **skeletal, cardiac** and **smooth** muscles.

The cytoplasm of muscle fibers or cells is called **sarcoplasm**. The endoplasmic reticulum of fibers or cells is called **sarcoplasmic reticulum**. The plasmalemma of fibers or cells is called the **sarcolemma**. Individual muscle cells are called **myocytes**.

Connective tissue arrangements of skeletal muscles

In skeletal muscles the myofibers are bound together in a similar manner to wires in a telecommunications cable. The connective tissue in the muscle serves to bind and integrate the action of the various contractile units. A thin and delicate

connective tissue layer, known as the **endomysium**, surrounds each individual myofiber. Myofibers are grouped together in

bundles or **fascicles**, which are also surrounded by connective tissue, known as the **perimysium**. The fascicles are.
surrounded and bound together by a further connective tissue coating known as the **epimysium**.

Light microscopy of myofibers

Longitudinal sections of skeletal muscle fibers show repeated cross-striations after regular staining (H&E). The stained bands are called **A-bands**, and in between these are non-stained **I-bands**. If the same myofiber is examined by polarizing microscopy the A-bands are seen to be **birefringent** or **anisotropic** (bright against a dark background with crossed polars), whereas the I-bands are **non-birefringent** or **isotropic**. (The origin of nomenclature comes from these polarizing properties: **A** = **A**nisotropic, **I** = **I**sotropic). At higher magnifications it is possible to see a line in the middle of the I band, known as the **Z line**. Examination of a myofiber at high magnification shows that it is composed of many parallel **myofibrils**. The A and I bands, and Z lines are visible in the myofibrils. The unit between two Z lines is known as the **sarcomere**. The myofibrils consist of repeating strings of sarcomeres. The sarcomeres in adjacent myofibrils tend to be in parallel, resulting in the overall cross-striations of the myofibers. It is also possible in some cases to distinguish a less-stained region in the middle of the A-bands, known as the **H-band** (Hensen's band). The sarcomeres form the basic contractile units of the fibers.

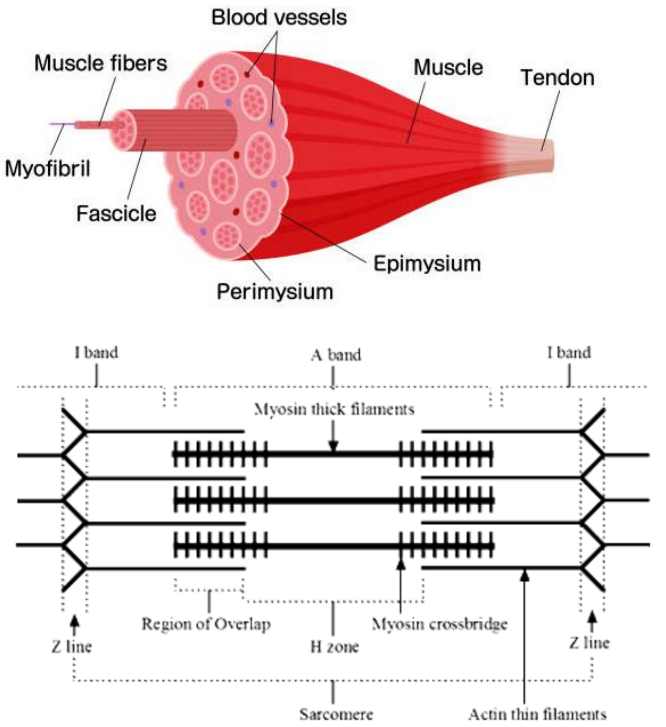

Figure 11. Structure of skeletal muscle and microscopy of myofibers.

Nervous tissue

There are two basic systems of internal communication and physiological homeostasis in the body: the **endocrine system** and the **nervous system**. The nervous system is derived from **embryonic neuroectoderm**. The nervous system is divided anatomically into: **Central Nervous System** (CNS), consisting of the brain and spinal cord; and the **Peripheral Nervous System** (PNS), consisting of nerve fibers, aggregates of nerve cells and glia and ganglia. Nervous tissue consists of two groups of cell types: **Nerve cells** (neurons) and **neuroglia**. The brain and spinal cord are composed of **gray matter** and **white matter**. **Gray matter** contains nerve cell bodies (perikarya), neuroglia, and a complicated network of cell processes (**neuropil**). **White matter** lacks nerve cell bodies (perikarya) but has

many processes of neurons. The white appearance is the result of the myelin that envelops many of the neuronal processes. Neuroglia are also found in white matter and the nuclei seen in white matter belong to neuroglia. In the Peripheral Nervous System (PNS), perikarya are found only in ganglia (apart from in some sensory regions such as the retina and olfactory mucosa).

Neurons

Neurons are post-mitotic structures that shortly after birth lose the ability to divide. Further changes involve only reduced number of neurons (neuronal death), or changes in volume or in neuronal connections. The functional unit of the nervous system is the **neuron**. Similar to the cell theory, which stipulates the cell as the basic building block of the body, the **Neuron Theory** describes the neuron as the basic building block of the nervous system, and that the nervous system functions through transmission of information through networks of neurons. Most neurons have three main parts: **dendrites, perikarya** (cell bodies) and **axon.**

Morphological classification of neurons

Neurons are classified according to the size, number and shape of their processes:

Unipolar (**pseudo-unipolar**) **neurons** have a single process (axon). These are found in sensory ganglia of the dorsal roots of spinal nerves.

Bipolar neurons have two processes (one dendrite and one axon). These are very rare and have a limited distribution in the body. They are present in special sensory structures including the retina, olfactory epithelium, and in vestibular and cochlear nerves).

Multipolar neurons possess several processes (several dendrites and a single axon). Most neurons belong to this category.

Neuroglia

Glia or **neuroglia** get their name from the Greek word for "glue". There is very little connective tissue in the CNS, and the structural

support for neurons comes from neuroglia and their processes. It is estimated that for every neuron there are at least 10 neuroglia, however, as the neuroglia are much smaller than the neurons, they only occupy about 50% of the total volume of nerve tissue. Neurons cannot exist or develop without neuroglia. There are **4 basic types of neuroglia**, based on morphological and functional features: **Astrocytes** (or Astroglia); **oligodendrocytes** (or Oligodendroglia); **microglia;** and **ependymal cells.** The astrocytes and oligodendroglia are large cells and are collectively known as **Macroglia**.
Note that neuroglia differs from neurons: Neuroglia have **no action potentials** and cannot transmit nerve impulses; neuroglia **are able to divide** (and are the source of tumors of the nervous system); neuroglia **do not form synapses;** neuroglia **form the myelin sheathes** of axons.

Functions of neuroglia

I. Structural support (especially the astrocytes in the CNS).
II. Participation in the blood-brain-barrier (astrocytes).
III. Formation of the myelin sheath of axons (oligodendrocytes).
IV. Isolation of junctional surfaces of synapses.
V. Repair processes following damage or injury to nerves.

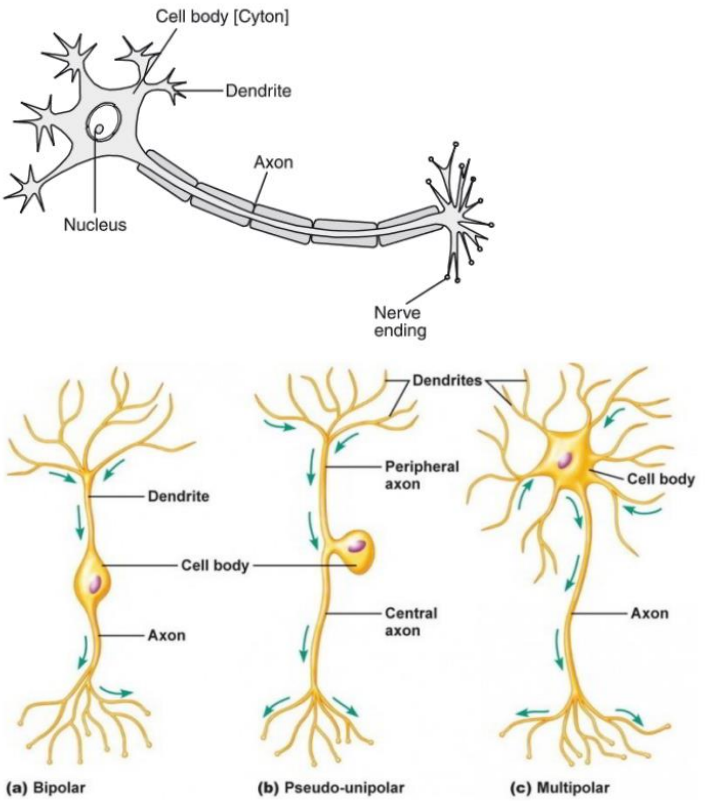

Figure 12. Diagrams showing the structure and morphological classification of neurons.

Connective tissue of peripheral nerves

Examination of a peripheral nerve shows a thin connective tissue layer surrounding each individual fiber. This is the **endoneurium** (also known as the sheath of Key and Retzius). Fibers are grouped in bundles, which are also surrounded by a connective tissue layer, known as the **perineurium**. The **epineurium** is a more extensive connective tissue layer between the bundles and extending to the most peripheral parts of the nerve. Nerves possessing only sensory fibers are called **sensory nerves**, whereas nerves possessing only motor fibers are called **motor**

nerves. Most nerves are **mixed nerves** in that they possess both sensory and motor fibers.

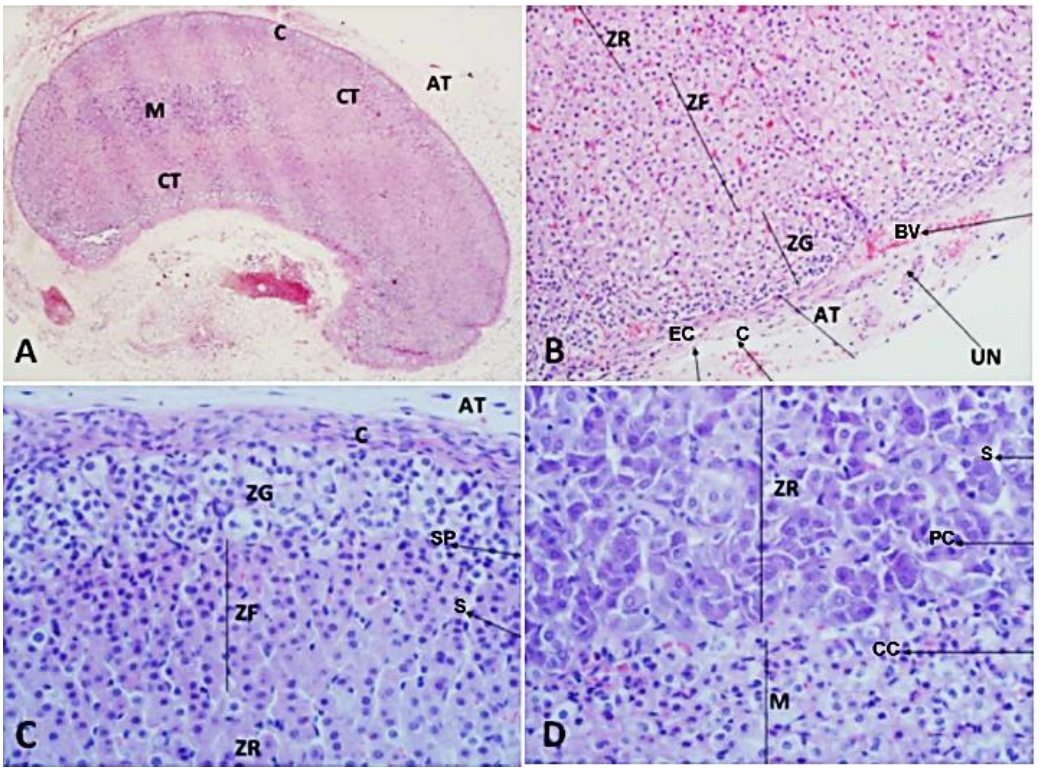

Figure 13. Photomicrograph of the adrenal gland of the African giant rat (*Cricetomys gambianus*)

A. Adipose tissue: AT; Capsule: C; Cortex: CT; and Medulla: M. x40 (H&E). (Olukole *et al.*, 2016).

B. AT:Adipose Tissue; BV: Blood Vessel; C: Capillary; EC: Epithelial cells; UN: Unmyelinated Nerve; ZG: Zona Glomerulosa; ZF: Zona Fasiculata ZR: Zona Reticularis. X100 (H&E).

C. Adipose tissue: AT; Capsule: C; Sinusoids: S; Spongiocyte: SP; Zona Glomerulosa: ZG; Zona Fasiculata: ZF and Zona Reticularis: ZR. X400 (H&E).

D. Chromaffin Cells: CC; Pigmented Cells: PC; Sinusoids: S; Medulla: M and Zona Reticularis: ZR. X 400 (H&E).

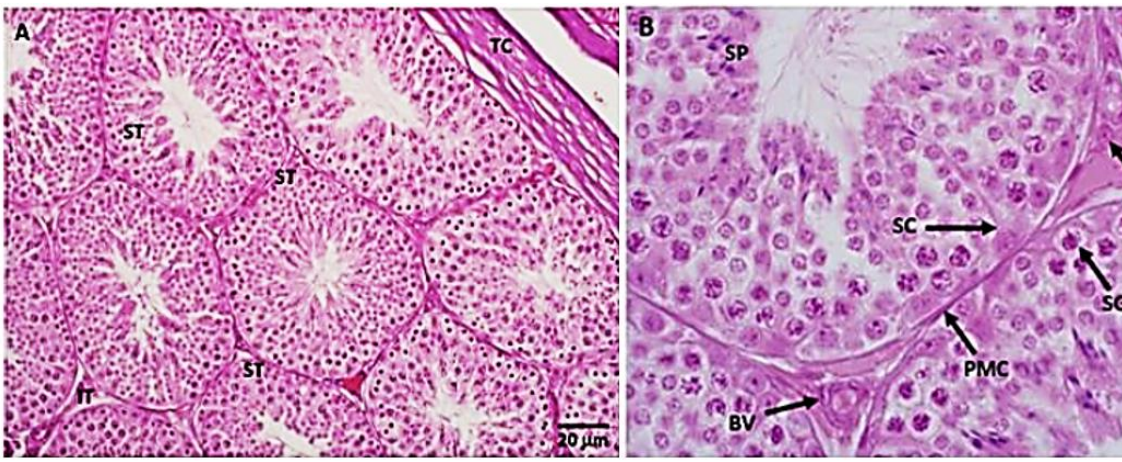

Figure 14. Photomicrographs of the testis of the African four-toed hedgehog (H&E). **A:** testicular capsule (TC), seminiferous tubule (ST) and interstitial tissue (IT). **B:** spermatocyte (SP), Sertoli cell (SC), blood vessel (BV), peritubular myoid cell (PMC), spermatogonium (SG), Leydig cell (LC).

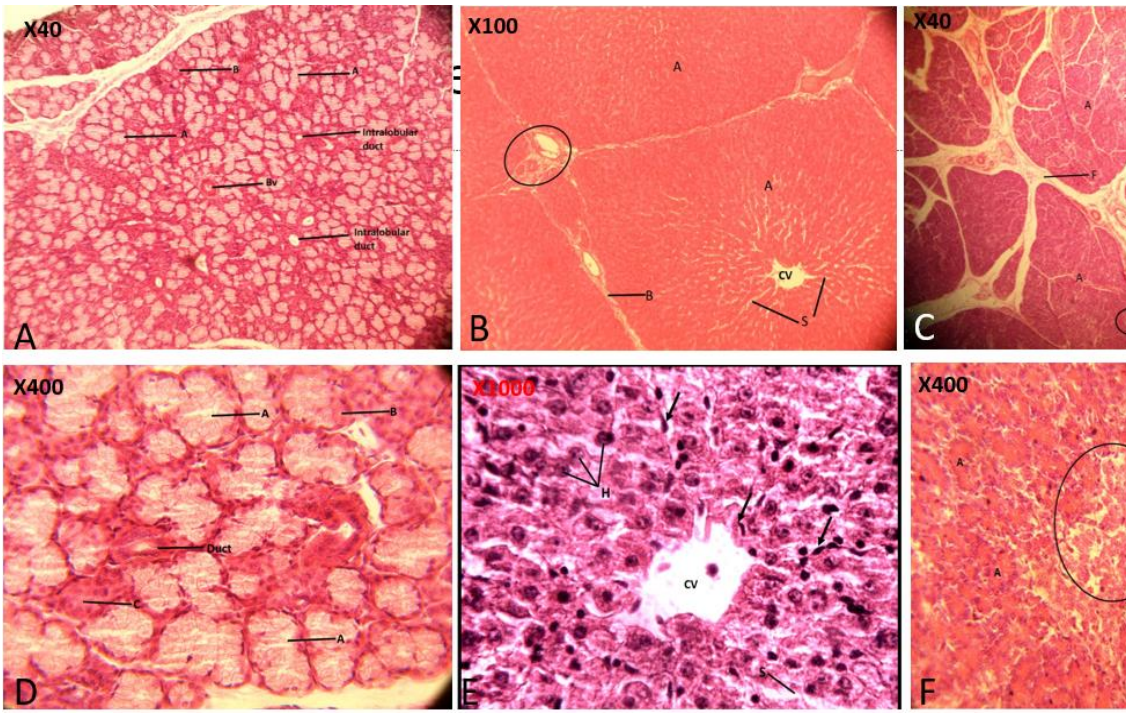

Figure 15. Photomicrograph of parotid salivary gland, liver and pancreas. A & D (Parotid salivary gland of rat): Characterized by the presence of mucous acini (A); serous demilunes (B); blood vessels (Bv); serous acinus (C) and different types of ducts: interlobular duct within the interlobular connective tissue, and striated duct within the lobules. B & E (Liver of squirrel): Note the hepatic portal triad (encircled area), containing hepatic artery, bile duct and portal vein, within the interlobular connective tissue. Radiating from the central vein (CV) are sheets of hepatocytes, interspersed by sinusoidal spaces called sinusoids (S). C & F (Pancreas of squirrel): Pancreatic acini (A); pancreatic Islets (encircled area). (Azeez *et al.*, 2022)

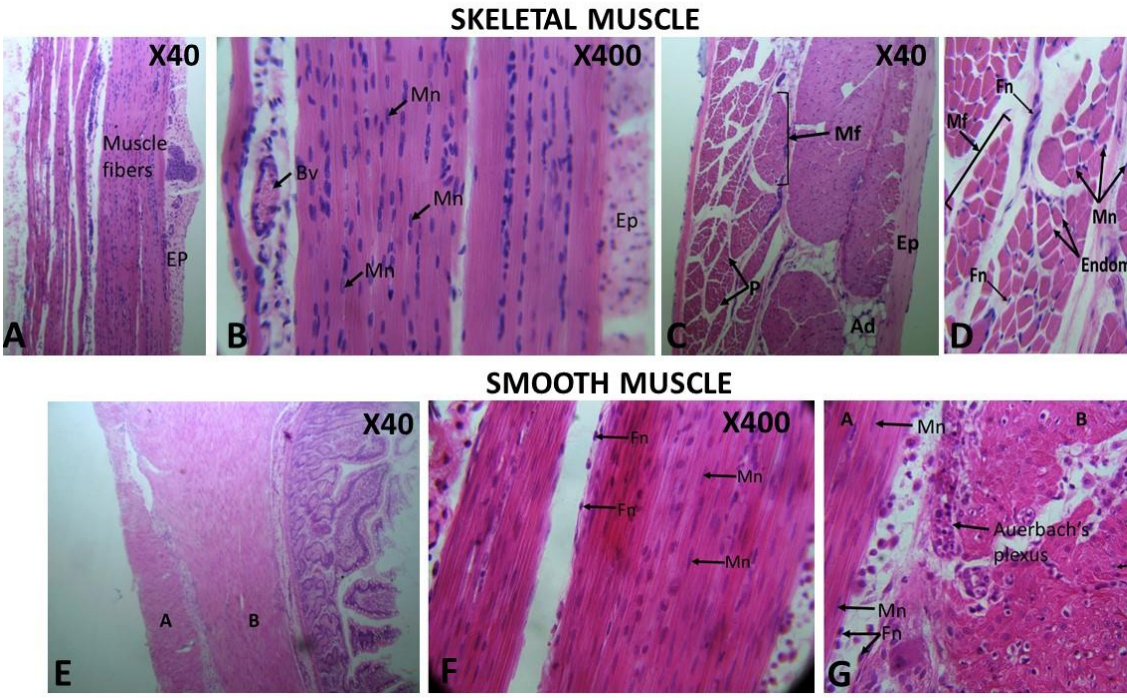

Figure 16. Photomicrograph of skeletal and smooth muscles. A&B (Longitudinal section of skeletal muscle – denoted with letter A), C & D (transverse section of skeletal muscle - denoted with letter B). Note that both sections are characterized by striated muscle fibers with peripherally placed myocyte nuclei (Mn); intramuscular nerve branch (Inb) and blood vessels (Bv), perimysium (P) separates one fascicle from the other, epimysium (Ep) covers the entire muscle tissue. E, F and G (longitudinal and transverse sections of smooth muscle respectively): Myocyte nuclei (Mn) are usually large, spindle-shaped in outline and centrally placed in longitudinal section while it is somewhat spherical and also centrally located in transverse section. The Fibroblast nuclei (Fn) are distinguished from Mn due to their darkish and small nuclei nature. Also note the Myenteric (Auerbach's plexus), between the longitudinal and transverse sections. Stain: H & E; Magnifications: X40 & X400.

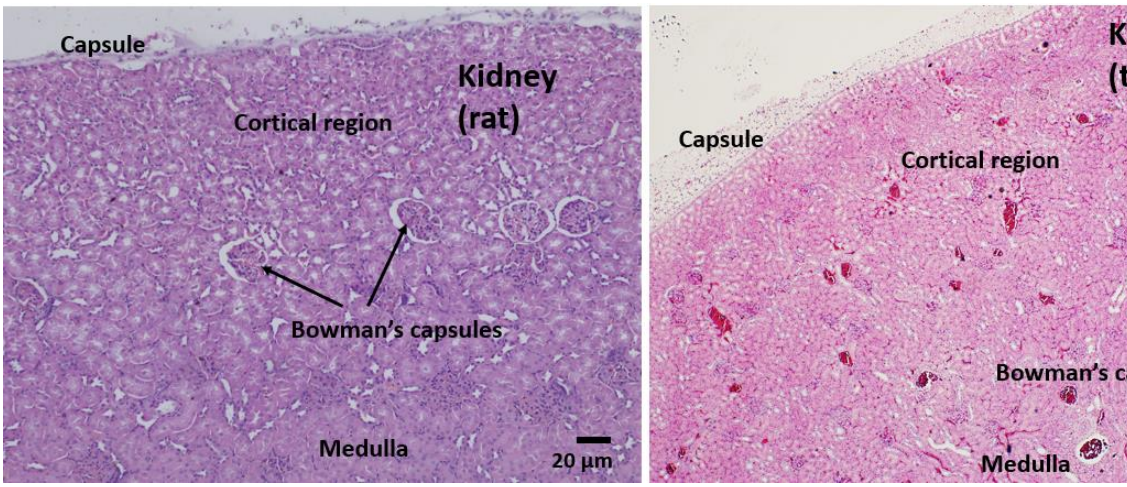

Figure 17. Micrographs of the kidney of rat and turtle (H & E).

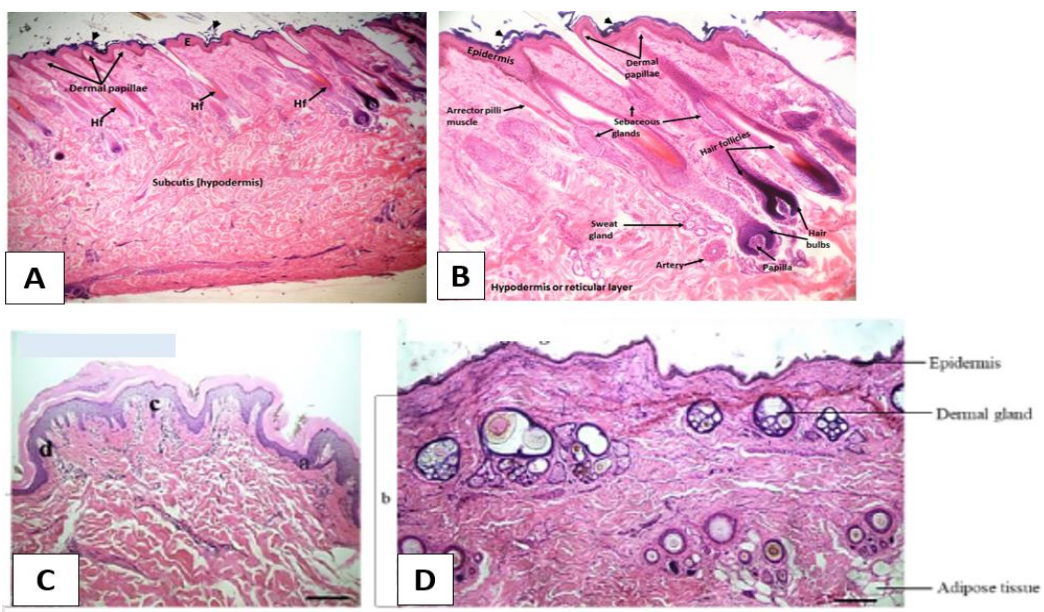

Figure 18. Photomicrographs of the skin of rat, pig and dog. Note that the skin is composed of the epidermis (E), dermis and hypodermis. The

epidermis consists of five layers in the thick skin in rat (A), dog (B) and more remarkable in pig (C) and 3-4 layers in thin skin. It is made up of stratified squamous epithelium-keratinized (arrowheads). The dermis starts from the dermal papillae and houses the arrector pili muscles, sebaceous glands, hair follicles (Hf) and numerous dermal glands especially in dog (D). The hair follicles extend into the hypodermis, where the hair bulb and papillae become visible. The dermis forms the vascular portion of the skin containing blood vessels, lymph vessels, nerves. Also visible in the dermis, extending to the hypodermis, are sweat glands. the hypodermis, also called the reticular layer or subcutis, consist mainly of adipose tissue, collagen and elastic fibers, with blood/lymph vessels and nerves. a: epidermis, b: dermis, c: epidermal peg and d: dermal papilla. Scale bar = 100 µm. (Azeez *et al*., 2023).

Summary:
This chapter has provided insight into the components of mammalian cells, cell surface modifications, cell-to-cell contact, cell cycle and cell division. It has also laid bare the concept of microscopy and microscopic techniques. Additionally, it elucidated on the knowledge of identification of the peculiar features of tissues that form the core of the building components of mammalian body. Finally, it has provided relevant histological sections that are specific to certain organ-systems in the mammalian body.

Exercises

1. List the various epithelial types and give three examples of their location in the body of animals.
2. Write an essay on microscopy.
3. How would you prepare histological slides from a living rat?
4. Writes extensively on cycle and cell division.

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Chapter 4

VPY 201: Veterinary Physiology I (Blood, Circulatory and Respiratory Systems)

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Overview

In order to sustain life, grow and multiply, organisms must respire and obtain nutrients from their environment, and also eliminate metabolic waste products. Single-celled organisms achieve all these simply by exchange through the cell membrane without any need for a circulatory system. Multicellular organisms, however, require an elaborate system to deliver nutrients and other important substances to each one of the trillions of cells in their body, as well as transport the waste products of cellular metabolism for elimination into the environment. The circulatory and respiratory systems are organised in such a way as to meet these life-sustaining needs in multicellular organisms, with blood as the common transport medium. There are some variations in the organisation of the systems among the different classes and species of animals, but the basic outcome is the same.

Objectives

The objectives of this course are to:

1. describe the functions, components and characteristics of blood, and the origins of its formed elements (cells).

2. describe the organs, tissues, cells, substances and mechanisms/processes that are responsible for the circulation of blood and lymph in the body, as well as the utilisation of oxygen and excretion of excess carbon dioxide.
3. present basic concepts, definition of terms and species differences in the physiology of blood circulation and respiration.
4. explain the clinical implications of common abnormalities in the systems.

Blood

Introduction

Blood is a specialised body fluid that is pumped by the heart to circulate in arteries, veins and capillaries. It is responsible for the exchange of gases and nutrients and the removal of waste products of metabolism from cells. Blood is described as a connective tissue because it is made up of cellular elements and an extracellular matrix. The cellular elements also referred to as the formed elements, include red blood cells (RBCs or erythrocytes), white blood cells (WBCs or leucocytes), and platelet (thrombocytes), while the extracellular matrix, called plasma, is the fluid part of blood in which all the formed elements are suspended.

Functions of blood

The function of blood is related to the need to bring the basic nutrients/requirements from the external environment to the cells and the disposal of the waste products from the cells. Blood, therefore, performs the basic function of transporting various materials around the body.

In brief, the functions of blood are discussed under the following categories:

1. Respiration: Blood serves as a transport medium for respiratory gases (oxygen and carbon dioxide).

2. Nutrition: Blood transports nutrients (such as glucose, amino acids, fatty acids, vitamins and electrolytes) from the gastrointestinal tract to body tissues.
3. Excretion: Blood transports waste products of metabolism (such as urea, creatinine, uric acid and bilirubin), drugs and their metabolites etc., to the organs or tissues where they are metabolised (liver) and/or excreted (kidneys).
4. Homeostasis: Blood helps in the maintenance of a constant internal environment.
5. Temperature regulation: Blood helps in distributing or dissipating heat from one part of the body to the other, thus maintaining a constant body temperature (homeothermy).
6. Hormonal regulation: Blood participates in the transportation of endocrine hormones to their target organs for the regulation of various body functions.
7. Protection: Blood participates in cell-mediated and humoral immunity by transporting WBCs to combat invasive organisms. It also clots (coagulates) to plug injured blood vessels.

Composition of blood

Blood is composed of:

a) Cells (Figure 1), which are in three categories:
   - Erythrocytes (red blood cells). They transport respiratory gases.
   - Leucocytes (white blood cells), sub-divided into granulocytes (neutrophils, eosinophils, and basophils) and agranulocytes (monocytes and lymphocytes) They help to fight infection and foreign pathogens.
   - Thrombocytes (platelet): Help the blood to clot and stop bleeding.

b) Plasma, which is made up of about 93% water and 7% dissolved solutes. The dissolved solutes include plasma proteins (albumin, globulins, and fibrinogen), nutrients (glucose, amino acids and triglycerides), electrolytes (e.g., Na^+, Cl^-, HCO_3^-, K^+, Ca^{2+})

enzymes, vitamins, trace elements, waste products of metabolism (e.g., urea, creatinine, bilirubin), hormones and antibodies.

Plasma proteins are mainly produced by the liver, but some immunoglobulins are produced in lymph nodes, spleen, and bone marrow.

Plasma proteins:

- Serve as sources of amino acids for the synthesis of tissue proteins.
- Help in the maintenance of colloidal osmotic pressure and fluid balance.
- Serve as blood buffers to regulate acid-base balance.
- Are essential for coagulation of blood after haemorrhage.
- Assist in the suspension and stability of red blood cells in the blood.
- Help to maintain stable blood viscosity, especially gamma globulins.
- Serve as carrier proteins in the transport of ions, hormones, vitamins etc.
- Provide antibodies against specific antigens (immunoglobulins).

***How to measure packed cell volume and obtain plasma and serum*:** When blood is collected into tubes that contain anticoagulants (which prevent blood from clotting) and centrifuged, the RBCs settle at the bottom while the WBCs and platelets form a thin layer above the RBCs, called the buffy coat, and plasma stays on top as the supernatant. *Packed cell volume* (PCV) can now be measured as the per cent volume of blood that is occupied by the RBCs. The PCV is an important marker of health because many diseases affect its value since RBCs are very fragile. When blood is collected without an anticoagulant, the blood clots (coagulates). When clotted blood is centrifuged, serum is obtained as the supernatant fluid. Serum is similar to plasma, except that it lacks all the clotting factors (especially fibrinogen) which have formed part of

the clot. Serum may be used in the place of plasma to analyse blood components that are not affected by the clotting process.

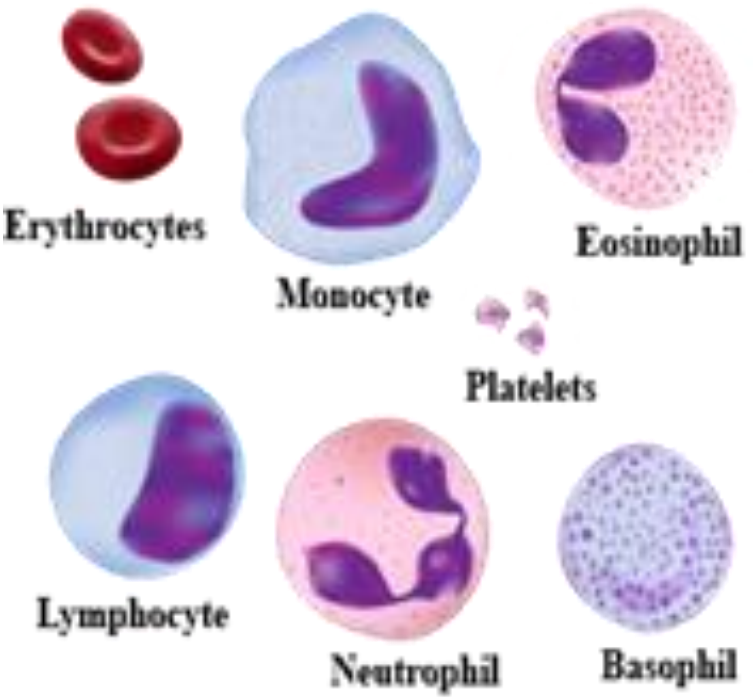


Figure 1: Mature mammalian blood cells

Erythrocytes

Mature mammalian RBCs are biconcave, circular, non-nucleated (nucleated and oval-shaped in non-mammalian vertebrates like birds, amphibians, reptiles, and fish), and are responsible for the transportation of oxygen and carbon dioxide in the blood. The

mammalian RBC contains about 62 – 72% water and 35% solids. Of the solids, 95% is contributed by *haemoglobin* and the remaining 5% by cell and stromal proteins, lipids, phospholipids, cholesterol, cholesterol esters, neutral fats, and vitamins. Each RBC is packed with millions of haemoglobin molecules. The lack of organelles in the mature erythrocytes of mammals leaves more room for the haemoglobin molecules. Haemoglobin is an iron-containing protein that is responsible for the transport of most oxygen and some carbon dioxide in the red blood cell. It is made up of haeme and globin. Haemoglobin binds oxygen in the lungs to form oxyhaemoglobin, transports and releases it in the tissues, and thereafter picks up carbon dioxide from the tissue to form carbaminohaemoglobin and transports it to the lungs for elimination. Haemoglobin also stores oxygen, acts as a buffer for hydrogen ions and is responsible for the red colour of blood.

***Erythrocyte indices*:** Red blood cell indices provide information about the size of RBCs and their haemoglobin (Hb) content. Abnormal values indicate the presence and type of anaemia. Erythrocyte indices are estimated from values of PCV, RBC count and Hb concentration. These indices include:

a) Mean corpuscular volume (MCV) – the average size of the RBCs in the selected blood sample. It is expressed in femtolitres (10^{-15}; fL) or cubic microns (μm^3). It is calculated using the following formula:

$$MCV = \frac{PCV\ (\%) \times 10}{RBC\ count\ (million/\mu L)}$$

b) Mean corpuscular haemoglobin (MCH) – the average amount of haemoglobin in each RBC. It is expressed in picograms (ρg)/cell or $10^{-12}g$. It is calculated using the formula:

$$MCH = \frac{Hb\ (g/dL) \times 10}{RBC\ count\ (million/\mu L)}$$

c) Mean corpuscular haemoglobin concentration (MCHC) – the average amount of Hb in a single RBC as it relates to the

volume of the cell. It is expressed in g/dL. It is calculated using the formula below:

$$MCHC = \frac{Hb \times 100}{PCV}$$

***Erythrocyte sedimentation rate*:** This is the distance RBCs travel per hour in a sample of blood as they settle to the bottom of a standardised test tube. It is a non-specific indicator of inflammation, infection, cancer, rheumatic diseases, and diseases of the blood and bone marrow.

***Erythrocyte osmotic fragility*:** It is the propensity of RBCs to haemolyse (rupture) when subjected to osmotic changes such as suspension in hypotonic NaCl solutions. It increases during stress, ageing, inflammation and infection, exposure to xenobiotics and in hereditary spherocytosis.

White blood cells

Leucocytes are large, nucleated cells involved in the maintenance of immunity. They are divided into two broad groups based on the presence and visibility of granules or otherwise.

- Granulocytes, which include neutrophils, eosinophils and basophils, also called polymorphonuclear leucocytes. They have granules (small particles) with enzymes that are released during infections, allergic reactions, and asthma.
- Agranulocytes, which include monocytes and lymphocytes.

***Neutrophils*:** Also called heterophils in avian species, they are nucleated highly motile phagocytic cells. Usually the most numerous, constituting about 50 – 70 per cent of the total WBCs, except in some adult ruminants. They have neutral granules, which do not pick up stains and a segmented nucleus (usually 3 – 5 segments). The nucleus of neutrophils from female animals usually has a characteristic drumstick appearance at one pole that can be used for sex differentiation. Elevated neutrophil count (neutrophilia) is seen during excitement and fear, inflammation and acute bacterial infection. Reduced neutrophil count (neutropenia) is seen in viral and chronic bacterial infections.

Eosinophils: Constitute about 2 – 4 % of the total WBC count. It has red to orange or eosinophilic granules and a segmented nucleus (2 – 3 segments). It is also phagocytic. *Eosinophilia* is seen in parasitic worm infestation, allergies and autoimmune diseases, while *eosinopenia* is seen in stress.

Basophils: These are the least common leucocytes with usually bi-lobed nucleus with large dark-blue or purple granules. Basophil granules, like those of mast cells, contain histamines and heparin. Increased basophil count above normal (basophilia) is associated with allergies, parasitic infections, and hypothyroidism, while abnormally decreased counts (basopenia) may be associated with pregnancy, stress, chronic infection or hyperthyroidism.

Lymphocytes: These include small and large lymphocytes with a round nucleus and a thin rim of cytoplasm. They are non-phagocytic but are capable of amoeboid movement. These cells are concerned with the development of immunity against specific disease organisms. Lymphocytosis (increased lymphocyte count above normal) is seen in and stress, while lymphopenia is seen in chronic immunosuppression and the use of steroidal anti-inflammatory drugs.

Monocytes: These are the largest of leucocytes, with kidney- or bean-shaped nuclei. They are actively motile and highly phagocytic. They migrate into tissue spaces and become macrophages, with specific names and features in different tissues. They are capable of phagocytising pathogens, effete cells and cell debris or forming giant cells and epithelioid cells in chronic granulomatous inflammation. An increased number of monocyte counts (monocytosis) is seen in haematological malignancies, endocarditis, typhoid, tuberculosis, brucellosis and prolonged blood parasitic infections like trypanosomosis.

Thrombocytes: Platelet are cell fragments in mammals. They are non-nucleated cytoplasmic fragments covered by cell membranes and originate from megakaryocytes – a giant cell in the bone marrow. They

are, however, nucleated elliptical cells in birds and reptiles. Their main function is the formation of a haemostatic plug to stop haemorrhage following damage to a blood vessel. They also secrete a variety of growth factors essential for growth and repair of tissue. Elevated platelet count, known as thrombocytosis, can be seen in splenectomy and haemolytic anaemia, while thrombocytopenia is seen in aplastic anaemia and myelophthisis, autoimmune thrombocytopenia, excessive thrombocyte consumption seen in disseminated intravascular coagulation and hypersplenism.

***Factors affecting haematological parameters*:** Haematological parameters are influenced by various factors, which cause their variation, even in the same animal species. These include age, sex, time of the day, exercise, pregnancy status, nutrition, season, environmental temperature, health status, altitude and blood volume. The factors must, therefore, be taken into consideration when interpreting these parameters.

Haematopoiesis

This is the formation of blood cellular components. All cellular blood components are derived from haematopoietic stem cells (Figure 2). In healthy adult animals, billions of new blood cells are produced per day, in order to maintain steady-state levels in circulation.

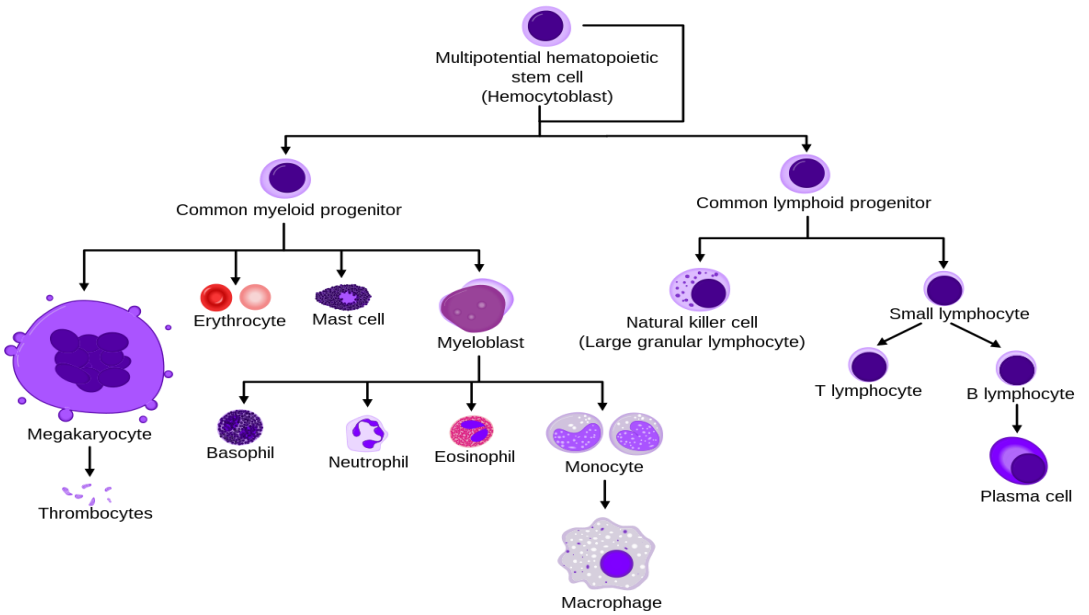


Figure 1: Formation of blood cells from haematopoietic stem cells

Erythropoiesis: This is the process of formation of erythrocytes in the bone marrow. It begins in the yolk sac, foetal liver, spleen, lymphatic tissue (extramedullary erythropoiesis), and the red bone marrow (medullary erythropoiesis). In adult animals, erythropoiesis is limited to the red bone marrow in flat bones and epiphysis of long bones. However, extramedullary haemopoiesis can take place in the liver and spleen in adult animals in cases of bone marrow destruction or cancer. Erythropoietin is the hormone that stimulates RBC production. The stages of erythropoiesis include proerythroblast, erythroblast, normoblast, reticulocyte, and erythrocyte (fully mature RBC).

The fate of the RBC: RBCs, after differentiating from erythroblasts in the bone marrow, are released into the blood and survive in circulation for up to 120, 45 and 35 days in humans, mice and chicken, respectively.

The life span varies from 70-160 days in domestic mammalian species although it is often shorter in juvenile animals (e.g., calves and lambs) compared to adults. RBCs in small animals have a shorter life span than in the larger domestic species. Removal of ageing, dead or deformed RBCs from the circulation occurs through phagocytosis (erythrophagocytosis), which takes place mainly in macrophages of the spleen, but also in the liver and the bone marrow. In those species in which phagocytosis is negligible, the RBCs are fragmented one by one, while still circulating, to fine, haemoglobin-containing dust. The cell fragments are then rapidly removed from the blood.

Leucopoiesis and Thrombopoiesis: The granulocytes and the megakaryocytes (which form the thrombocytes) are produced from the myelocytes of the bone marrow while lymphocytes (large and small lymphocytes and plasma cells) are formed from the lymphoid tissues. Monocytes are produced by the mononuclear phagocytic system (MPS) cells of the spleen and bone marrow (reticuloendothelial system cells).

Anaemia**:** is the reduction in the number of RBCs and/or Hb concentration per unit volume of blood below the normal range. The main types are *microcytic* (small-sized RBCs) *normocytic* (normal-sized RBCs), and *macrocytic* (bone marrow makes RBCs that are larger than normal) anaemia. Causes include haemorrhage, blood-sucking parasites, haemolysis or defective production of RBCs.

Polycythaemia**:** This is an increased quantity of RBCs in the blood. It could be relative or absolute. It is relative when the animal is dehydrated, and absolute when there is an elevated RBC production. Absolute polycythaemia may result from an increased need for oxygen as seen in animals living at high altitudes, racehorses and race dogs. It can also occur when erythropoietin level is increased due to cancer; or in myeloproliferative disorder and polycythaemia vera (a type of blood cancer), where the concentration of erythropoietin is normal.

Blood clotting (haemocoagulation)

It is the process by which liquid blood changes into semi-solid blood clots. It is the formation of a meshwork of fibrin threads that entrap blood cells, platelets and plasma through the activation of a series of clotting factors (Table 1) that are present in their inactive forms in the blood. It helps to prevent blood loss from damaged blood vessels.

Table 1: List of clotting factors in animals

Factor	Name	Source
I	Fibrinogen	Liver
II	Prothrombin	Liver*
III	Tissue thromboplastin	Damaged cells and platelets
IV	Ca^{2+} ion	Diet, platelets, bone matrix
V	Labile factor/Proaccelerin	Liver, platelets
VII	Serum prothrombin conversion accelerator/Proconvertin	Liver*
VIII	Antihaemophilic factor C	Platelets and endothelial cells
IX	Christmas factor/Antihaemophilic factor B	Liver*
X	Stuart factor	Liver*
XI	Plasma thromboplastin antecedent	Liver
XII	Hageman factor	Liver
XIII	Fibrin stabilising factor	Liver and platelets

* Requires Vitamin K

Blot clot formation is a sequence where one event prompts the next as in a multi-level cascade (Figure 3). Three stages of blood clotting include:

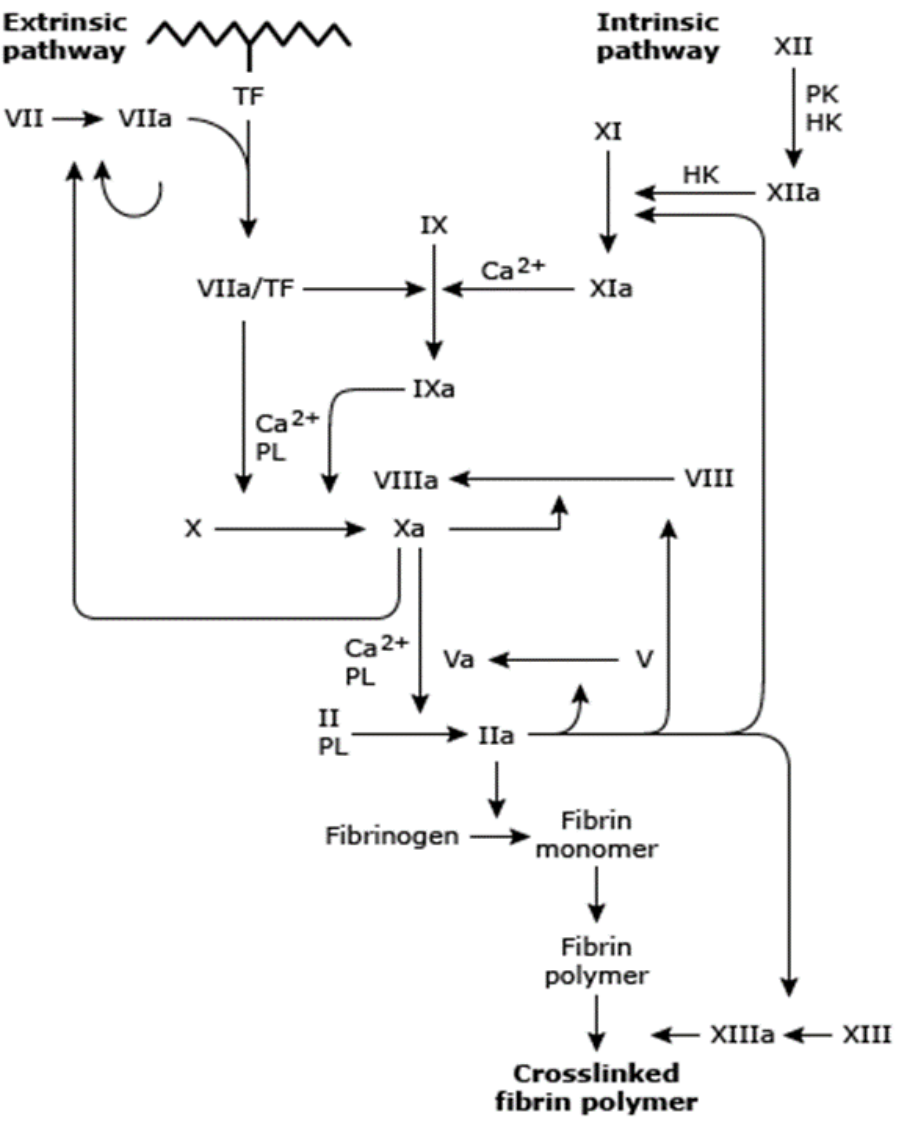


Figure 2: Blood clotting cascade

- Formation of prothrombin activator in response to rupture of a blood vessel or damage to the blood itself.
- Conversion of prothrombin into thrombin by the catalytic activity of the prothrombin activator.
- Conversion of fibrinogen into fibrin thread by the enzymatic activity of thrombin.

The two pathways for the initiation of blood clotting are:

a) Extrinsic pathway, usually triggered by trauma.
b) Intrinsic pathway, triggered by internal damage to blood vessels.

These two pathways, however, merge to form a common pathway.

Blood coagulation disorders are conditions that affect the blood's clotting activities. They include haemophilia, Willebrand disease, clotting factor deficiencies, hypercoagulable states, deep venous thrombosis and sweet clover poisoning.

The most common of them, haemophilia, is typically caused by a hereditary lack of a coagulation
factor, most often factor VIII.
Sweet clover poisoning is a common livestock problem that is seen when animals eat spoiled sweet clover hay or silage, which interferes with the metabolism and synthesis of vitamin K and results in deficiencies of clotting factors II, VII, IX and X.

A *prothrombin time* (PT) test measures how long it takes for a clot to form in a blood sample. A typical PT result is 10 – 14 seconds (humans), 11.0 – 15.5 s (dogs), 15.0 – 20.0 s (cats), 11.0 – 15.0 s (horses), 26.0 – 38.0 (cattle) and 18.7 – 28.0 s (rats). Higher than normal values mean the blood is taking longer than normal to clot and may be a sign of many conditions, including bleeding or clotting disorder due to lack of vitamin K or clotting factors. *Partial thromboplastin time* (PTT) is a related blood test that looks at how long it takes for blood to clot. It

can help tell if there is a bleeding problem or if the blood does not clot properly.

Blood type/group

The blood of animals of the same species may be classified into different types/groups based on the presence or absence of inherited antigenic substances on the surface of RBCs. These antigens may be proteins, carbohydrates, glycoproteins, or glycolipids, depending on the blood group system. The antigens elicit adverse agglutination reactions when the blood is introduced into individuals that do not recognise them, as occurs during a *blood transfusion*. *Erythroblastosis foetalis* is a haemolytic disease of the foetus and new-born that is caused by the destruction of neonatal RBCs by maternal antibodies that are formed in response to a foetal antigen. *Erythrocyte chimerism* is a condition whereby two RBC types (instead of one) are found in an individual animal as seen in bovine freematinism. Chimerism is believed to most often occur through placental anastomoses that enable a bi-directional exchange of haematopoietic stem cells.

The Circulatory System

Introduction

The circulatory system consists of the cardiovascular and lymphatic systems. There are two types of circulatory systems in animals: the open and the closed.

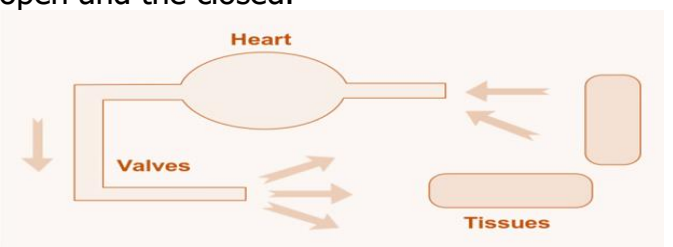
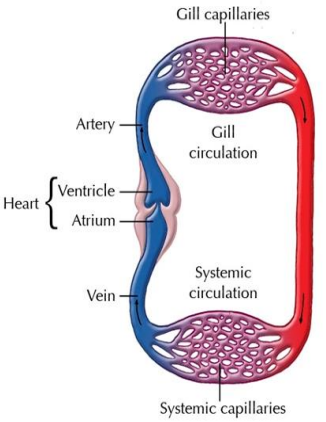


Figure 3: Open circulatory system

In open circulation (Figure 4), blood is not enclosed in vessels and is pumped into a cavity called haemocoel. The blood bathes the organs directly, supplying nutrients and oxygen, and removing wastes from the organs. Examples are found in invertebrates like crabs, insects and snails.

In closed circulation (Figures 5 and 6**),** the blood is transported by vessels from the heart in a single direction, delivering oxygen and nutrients to cells and removing waste products. The closed circulatory system can be single as seen in fish or double as seen in mammals and birds.



Functions of the cardiovascular system

The cardiovascular system has three general function: (1) Transportation (e.g., O_2, CO_2, nutrients, wastes, hormones); (2) Regulation (e.g., pH, temperature, osmotic pressures); and (3) Protection (e.g., against foreign molecules and diseases, as well as for clotting to prevent excessive loss of blood)

Figure 5: Single closed circulatory system in fish

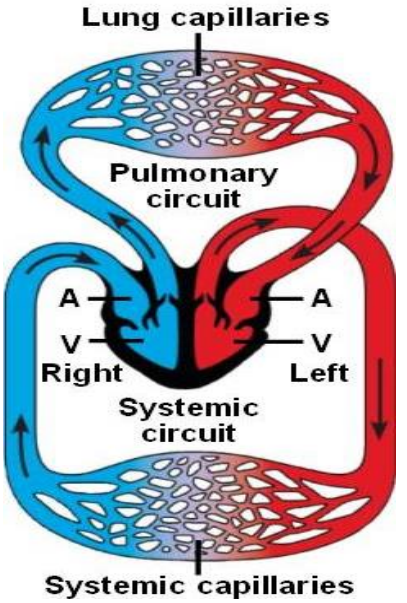


Figure 6: Double closed circulatory system in mammals and birds.

The organisation of the Heart in Mammals and Birds

The cardiovascular system consists of the heart (as a pump) and blood vessels. These are arranged in two pump series which maintain a continuous flow of blood around the body. The two pumps are (i) the left ventricle, providing blood flow to the systemic circulation and (ii) the right ventricle, providing flow to the pulmonary circulation. The output of the left ventricle is the same as that of the right ventricle, called the *cardiac output*. Cardiac output is the volume of blood pumped per ventricle per minute. *Stroke volume* is the volume of blood pumped per ventricle per beat. The cardiac output varies in different animals. The four determinants of cardiac output are heart rate, contractility, preload and afterload.

Valves in the Heart

There are valves in the heart that regulate the flow of blood within the chambers of the heart and between the chambers and major blood vessels (Figure 7). *Tricuspid valve* is present between the right atrium and right ventricle while the *bicuspid or mitral valve* is present between the left atrium and left ventricle. *Semilunar valves* regulate the flow of blood between the ventricles and the major blood vessels. The aortic valve is between the left ventricle and the aorta, while the pulmonary valve is present between the right ventricle and the pulmonary artery. Their function is to prevent the backflow of blood. The heart is covered by a sac called the *pericardium*, which contains a thin serous fluid that acts as a lubricant for the mechanical activity of the heart.

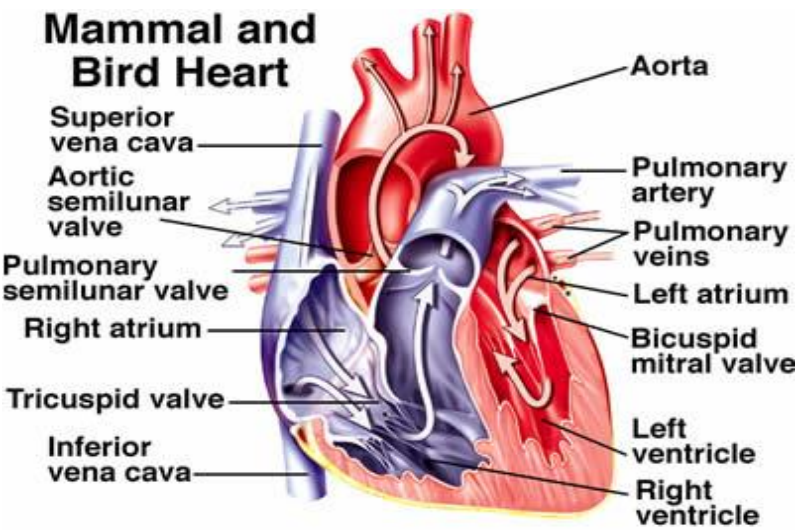


Figure 7: Birds and mammals have a 4-chambered heart (2 atria and 2 ventricles), with complete separation of oxygenated and de-oxygenated blood.

Types of Blood Vessels

The two kinds of blood vessels are the arteries and veins. Arteries carry blood away from the heart while veins bring blood to the heart. All arteries (except the pulmonary artery) carry oxygenated blood, while all veins (except the pulmonary vein) carry deoxygenated blood. The aorta and other large arteries are called *Windkessel vessels*, as they contain elastic tissue in their wall and hence, they recoil when stretched. The elastic recoiling of the aorta and large arteries is called the *Windkessel effect*. The small arteries and arterioles contain thick smooth muscle supplied by sympathetic noradrenergic fibres and offer peripheral resistance as they narrow down to the smaller arterioles, hence are called *resistance vessels***.** The resistance vessels end in capillaries. The capillaries are situated between arterial and venous systems. Capillaries are called *exchange vessels***,** as the exchange of respiratory gases, nutrients, metabolic wastes, etc., takes place between capillaries and tissues. The capillaries open into venules, which in turn end in veins. The venous blood from veins opens into large veins and then into vena cavae. The vena cavae opens into the right atrium of the heart. The venous system holds large amounts of blood (up to 55 - 60%) of total blood volume and are called *capacitance vessels***.**

Composition of the Heart

The heart predominantly consists of:

(i) Myocardial contractile cells or cardiomyocytes, which are involved in the mechanical activities of the heart.

(ii) The cells of the conducting system that are involved in the electrical activities of the heart which send signals to the heart muscle to contract. These include the sino-atrial (SA) node, atrio-ventricular (AV) node, bundle of His, right and left bundle branches, and the right & left Purkinje fibres (Figure 8).

The rhythmic contractions of the atria and ventricles are regulated by the transmission of electrical impulses that pass through the cardiac conduction system interposed within the contractile myocardium. The

SA node is a collection of specialised cells (pacemaker cells), located in the upper wall of the right atrium, where the superior vena cava enters. These pacemaker cells can spontaneously generate electrical impulses. The wave of excitation created by the SA node spreads via gap junctions across both atria, resulting in atrial contraction (atrial systole) – with blood moving from the atria into the ventricles. After the electrical impulses spread across the atria, they converge at the AV node (located within the AV septum). The AV node acts to delay the impulses by approximately 120ms, to ensure the atria have enough time to fully eject blood into the ventricles before ventricular systole. The wave of excitation then passes from the AV node into the bundle of His.

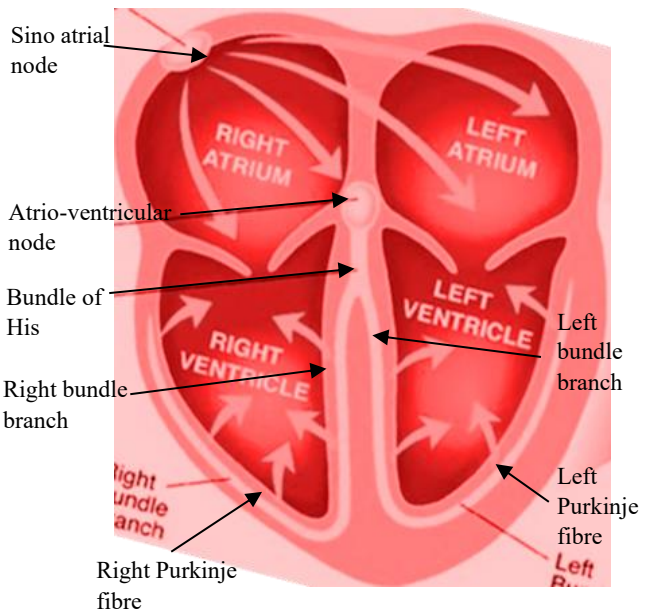


Figure 8: The heart with the electrical conducting cells.

The Bundle of His shortly divides to right and left bundle branches. It transmits the electrical impulse from the right and left bundle branches to the right and left Purkinje fibres of the ventricles respectively. Purkinje fibres are sub-

endocardial plexus of conduction cells which rapidly transmit cardiac action potentials from the AV bundle branches to the myocardium of the ventricles. This rapid conduction allows coordinated ventricular contraction (ventricular systole) and blood is moved from the right and left ventricles to the pulmonary artery and aorta, respectively. Purkinje is the fastest conduction cell out of the four special cells.

Properties of Cardiac Muscle

1. Rhythmicity/Automaticity/Chronotropism – the ability of the cardiac muscle (myocardium) to depolarise spontaneously, without external electrical stimulation from the nervous system.
2. Excitability (Bathmotropism) – the ability of the cardiac muscle to respond to adequate stimuli by generating an action potential.
3. Contractility/Inotropism – the ability of the cardiac muscle to convert electrical energy into mechanical work.
4. Conductivity (Dromotropism) – the ability of cardiac muscle fibres to conduct the cardiac impulses that are initiated in the SA node (the pacemaker of the heart)

All-or-None Law due to the Functional Syncytium of the Cardiac Muscle

The all-or-none law is the principle that if a single excitable tissue is stimulated, it will always give a maximal response and produce an electrical impulse (action potential) of a single amplitude. If the intensity or duration of the stimulus is increased, the height of the impulse will remain the same. By the all-or-nothing principle, an effective stimulus anywhere in the heart always activates the entire structure of the heart. This is because the cardiac muscle behaves as a functional syncytium. Action potentials initiated in one cell will spread to all other cells through the latticework of cellular interconnections.

Electrocardiogram (ECG)

Electrocardiography is the process of recording the electrical activity of the heart, which is conducted on the surface of the body (ions in body

fluid convert the body into a volume conductor). When electrodes are placed at appropriate positions on the body, ECG is recorded. A normal recording of an ECG wave shows P, QRS, and T waves; sometimes a U wave is also recorded (Figure 9). ECG is measured by placing electrodes directly on the skin and reading the potential difference between them. The two main leads in current use are the bipolar limb leads I, II, and III and the unipolar limb leads aVR, aVL and aVF according to Einthoven's law.

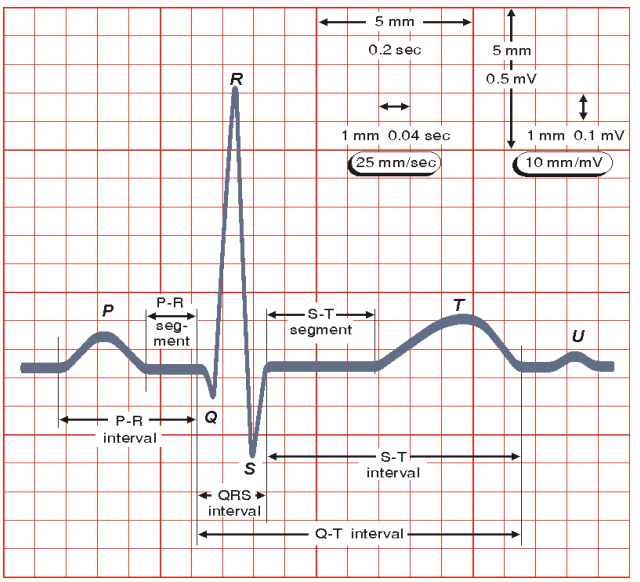
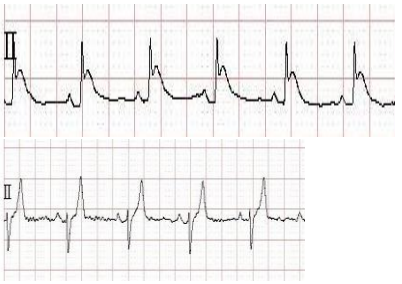


Figure 9: Normal electrocardiogram showing:
P wave = Atrial depolarisation, QRS complex = ventricular depolarisation, T = ventricular repolarisation, PR segment = area of delay after depolarisation of atria and before ventricular depolarisation.

Note- An electrode is a conductive pad that is attached to the skin and enables recording of current. An ECG is the graphical description of the electrical activities of the heart, created by analysing several electrodes.

Method of carrying out ECG in various animals: Rodents are given anaesthesia while other animals can be restrained to the convenience of the recorder and the animal. Recording is done on a non-conducting surface. Digital electrocardiographs are now available in various forms carrying five leads. One electrode is designated for each of the four limbs and the heart. Each of the electrodes is connected to the corresponding area after gel must have been applied. If the animal is very hairy, there may be need to shave to allow direct contact with the skin.

The digital electrocardiograph has been programmed to display 6 leads- I, II, III, aVL, aVR aVF. Resting ECG recording is done for 1 minute; Heart rate variability recording is done for 5 minutes. There are lots of variations in ECG of different species of animals. It can follow three general characteristics: 1. Relative duration of QT interval and ST segment 2. QRS-vector direction and
3. Constancy of T-wave polarity (T-wave lability). Rodents (e.g., rats, mice, Figure 10), bats, and insectivores have no ST segment in their normal ECG. QRS is normally inverted in birds (Figure 12).



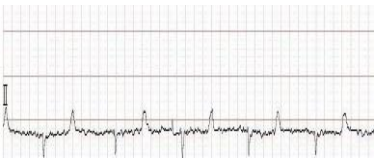


Fig 10: Normal ECG in rat Fig 11: Normal ECG in goat Fig 12: Normal

Heart Sounds and Murmurs

Heart murmurs are blowing, whooshing, swishing, or rasping sounds that are heard during a heartbeat, caused by rapid, turbulent (rough) blood flow through the heart valves or near the heart.
The sounds can be heard with a stethoscope. A typical heartbeat makes two sounds like "lubb-dupp" when the heart valves are closing. When a stethoscope is placed on the chest over different regions of the heart, there are four basic heart sounds (S_1, S_2, S_3 and S_4) that can be heard. Listening to heart sounds is called cardiac auscultation. The main normal heart sounds are the S1 and the S2. The S3 can be normal, at times, but may be pathologic. An S4 heart sound is almost always

pathologic. Heart sounds can be described by their intensity, pitch, location, quality and timing in the cardiac cycle. Sounds can be heard during heart muscle contraction (systolic murmur) and relaxation (diastolic murmur), and throughout the cardiac cycle (continuous murmur).

Blood Pressure

Blood pressure is the force applied on the arterial walls as the heart pumps blood into circulation. The rhythmic contractions of the left ventricle result in cyclic changes in blood pressure. During ventricular systole, the heart pumps blood into circulation, and the pressure within the arteries reaches its highest level; this is called *systolic blood pressure* (SBP). During diastole, the pressure within the arterial system falls and is called *diastolic blood pressure* (DAP). Blood pressure is measured in units called millimetres of mercury (mmHg). Mean arterial pressure (MAP) is normally considered a good indicator of tissue perfusion and can be calculated using the formula: MAP = DBP + PP/3 or MAP = DBP + (SBP – DBP)/3, where PP = Pulse Pressure.

Factors that affect blood pressure: Age, sex, posture, exercise, excitement, food digestion.

Fall in blood pressure can be seen in: Haemorrhage, heart failure, myocardial infarction.

Normal values of BP:
Dogs – Systolic 140, Mean 100, Diastolic 75 mmHg
Cats – Systolic 180, Mean 135, Diastolic 100 mm Hg
Horses – Systolic 110, Mean 90, Diastolic 70 mm Hg
Man – Systolic140, Mean 120, Diastolic 90 mmHg
Chicken – Systolic 180, Mean 140, Diastolic 130 mmHg

***Control of blood pressure*:** Neural control of blood pressure is a reflex mechanism involving baroreceptors (carotid and aortic)**,** vasomotor centre and arterioles. Long-term regulation of arterial blood

pressure involves renal mechanisms and hormones. The arterial blood pressure is regulated through electrolyte balance and maintenance of fluid volume with production of aldosterone and release of antidiuretic hormone (ADH).

Functions of the lymphatic system

The lymphatic system consists of the lymphatic vessels and the lymphoid organs (lymphatic nodules, lymphatic nodes, spleen and thymus). Lymphatic vessels contain and transport the lymph, which is collected from the tissues and organs of the body and released into a large vein. It protects the body from illness-causing invaders, maintains body fluid levels, absorbs digestive tract fats and removes cellular waste. It is a major part of the immune system.

Nervous Regulation of the Circulatory System

The regulation (control) of the heart and peripheral circulation by the nervous system is accomplished by control centres in the medulla that receive descending input from higher neural areas in the brain and afferent input from mechanically and chemically sensitive receptors located throughout the body. Nervous control affects functions, such as redistributing blood flow to different areas of the body, increasing the pumping activity of the heart and, especially, providing very rapid control of arterial pressure.

The Respiratory System

***The atmosphere, the organism and gas exchange*:** The earth's atmosphere contains a mixture of gas molecules that sustain life in organisms. The exchange of these gases between the organism and its environment is called respiration, while the respiratory system is the network of organs and tissues that ensure this exchange. There are four basic respiratory gases in the atmosphere, namely, nitrogen

(78.62%), oxygen (20.84%), carbon dioxide (0.04%) and water vapour (0.50%), but the primary exchange involves oxygen and carbon dioxide. Marine organisms, like fishes, extract oxygen from the amount that is dissolved in the surrounding water.

***Partial pressures of gases in a mixture*:** Partial pressure refers to the pressure that is exerted by a single gas in some given system (atmosphere, blood, tissue, lung or experimental mixture). The sum of the individual partial pressures produces the total pressure in the system, called barometric pressure. The barometric pressure of the atmosphere is 760 mmHg at sea level (Table 2).

Table 2: Partial and total pressures (mmHg) of respiratory gases in and around a resting animal at sea level

Respiratory Gases	Partial Pressures (mmHg)				
	Atmospheric air	Alveolar air	Venous blood	Arterial blood	Tissues/cells
Nitrogen	597	569	569	569	569
Oxygen	159	104	40	100	30 or less
Carbon dioxide	0.3	40	45	40	50 or more
Water vapour	3.7	47	47	47	47
Total Pressure	760	760	701	756	696

Pulmonary ventilation (breathing) is the exchange of air between the atmosphere and the lungs (or the movement of air into and out of the lungs). It depends on movements of the diaphragm and thorax, as well as clear airways (nasal cavity > pharynx > trachea > bronchi > bronchioles > alveoli). Ventilation in a resting mammal is brought about

by contraction of the diaphragm alone, which expands the thorax and lungs, lowers pressure inside the lungs, and draws in air (inhalation/inspiration); whereas relaxation of the diaphragm automatically causes the reverse effects leading to exhalation/expiration of air from the lungs. Under conditions that demand an increase in the rate of ventilation (e.g., exercise), the diaphragm must work with the external intercostal muscles to cause inhalation, while the abdominal and internal intercostal muscles contract to cause exhalation.

Since birds lack a diaphragm, they achieve inspiration by expanding the thorax, moving the ribs laterally, the sternum ventrally and cranially, and expanding the abdominal muscles. During exhalation, fresh air from the posterior air sac moves into the lungs, while stale air from the anterior air sacs is expelled through the bronchus and trachea. This pattern of airflow through the respiratory system of birds creates a unidirectional (one-way) flow of fresh air over the gas exchange surfaces in the lungs.

One ventilation cycle = one breath = one inhalation + one exhalation.

Respiratory rate is the number of breaths (ventilation cycles) per minute.

Pulmonary (lung) volumes refer to the volume of gas (air) in the lungs at a given time during the respiratory cycle. For ease in describing events of pulmonary ventilation, the air in the lung is subdivided into four different lung volumes which when added together equal the maximum volume to which the lungs can be expanded:

1. Tidal Volume (TV) – The amount of air that moves into or out of the lungs with each normal quiet inspiration or expiration respectively.
2. Inspiratory Reserve Volume (IRV) – The extra volume of air that can be inspired over and beyond the normal tidal volume.
3. Expiratory Reserve Volume (ERV) – The amount of air that can still be expired by forceful expiration at the end of a normal tidal expiration.
4. Residual Volume (RV) – The volume of air still remaining in the lungs after the most forceful expiration. It is important in aerating the blood in between breaths.

Species differences

1. In horses, exhalation does not occur without contraction of the expiratory muscles, even under resting conditions.
2. Horses, cats, rabbits and rodents cannot breathe through the mouth.
3. Respiratory Rate (breaths/min): Horse (10-40), Cattle (10-30), Sheep, Goat and Cat (20-30), Pig (8-18), Dog and Chicken (15-30), Rabbit (30-40), African giant rat (26-174).
4. Lung volumes and capacities vary with species.
5. Air sacs are unique to birds and airflow in their lungs is unidirectional.

Pulmonary capacities are derived from a summation of different lung volumes as follows (Figure 13).

1. Inspiratory Capacity = TV + IRV. The maximum amount of air that can be inspired after a normal tidal expiration.
2. Functional Residual Capacity = ERV + RV. The amount of air remaining in the lungs at the end of normal tidal expiration. It is

important in aerating the blood in between breaths during normal respiration.

3. Vital Capacity = TV + IRV + ERV. The maximum amount of air that can be expired from the lungs after a maximum inspiration.
4. Total Lung Capacity = TV + IRV + ERV + RV. The total amount of air in the lungs after a maximum inspiration.

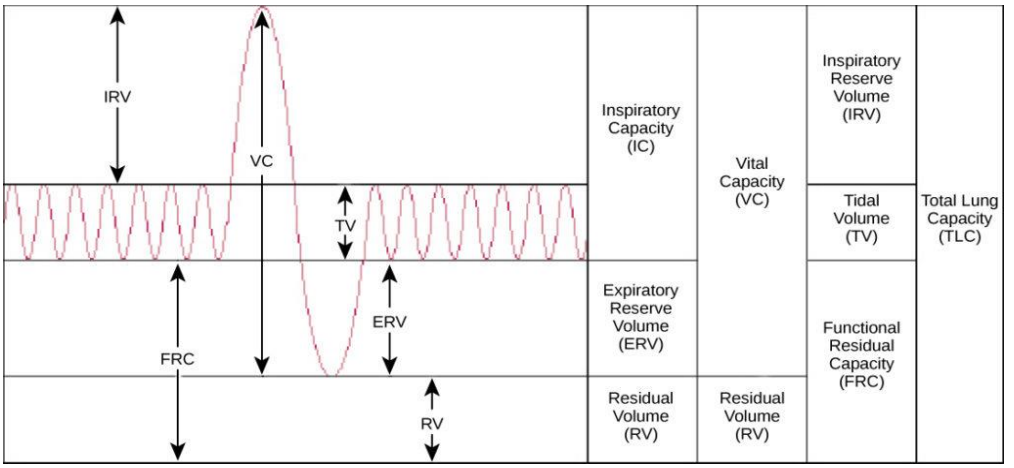


Figure 13: Lung volumes and capacities

Lung (pulmonary) compliance refers to the ability of the lungs to stretch and expand. It can be calculated by dividing volume by pressure. Two factors affecting lung compliance are elasticity from the elastin in connective tissue, and surface tension which is decreased by surfactant production. Lung compliance opposes the outward pull of thoracic wall compliance. The net compliance (lung-thoracic wall system) allows the lungs to achieve appropriate functional residual capacity, the volume remaining after passive expiration.

A surfactant is an agent that decreases the surface tension between two media. The surface tension between gaseous-aqueous interphase

in the lungs is decreased by the presence of a thin layer of fluid known as *pulmonary surfactant*. It is produced by the alveolar type-II cells of the lungs.

The *Hering–Breuer* inflation reflex, named after Josef Breuer and Ewald Hering, is a reflex triggered to prevent the over-inflation of the lung. Pulmonary stretch receptors present on the wall of the bronchi and bronchioles of the airways respond to excessive stretching of the lung during large inspirations. The reflex is initiated by lung expansion, which excites stretch receptors in the airways. Stimulation of these receptors, which send signals to the medulla by the vagus nerve, shortens inspiratory times as tidal volume (the volume of air inspired) increases, accelerating the frequency of breathing.

External respiration is the exchange of gases in the lungs between alveolar air and the blood of the pulmonary circulation. This process depends on gas partial pressure differences, the integrity of lung membranes and blood flow in and out of the lungs. Oxygen diffuses from alveolar air into pulmonary capillary blood, while carbon dioxide moves in the opposite direction by simple diffusion. This gaseous exchange occurs at the *respiratory membrane*, which consists of the alveolar wall and the capillary wall that separates air within the alveoli from the blood within the pulmonary capillaries. The *diffusion capacity* of carbon dioxide across this membrane is about 20 times that of oxygen, but the partial pressure gradient is normally only about 5 mm Hg for carbon dioxide, whereas it is about 60 mm Hg for oxygen. A key difference in birds is that gas exchange occurs in rigid tubes, through which air flows unidirectionally during both inspiration and expiration.

Internal respiration is the exchange of gas between the blood of the systemic circulation and the cells of the body. This process generally depends on the same factors as external respiration, whereby oxygen diffuses from the blood into cells, while carbon dioxide moves in the opposite direction.

Cellular respiration is the process by which organisms combine oxygen with foodstuff molecules, diverting the chemical energy in these substances into life-sustaining activities and discarding, as waste products, carbon dioxide and water (O_2 + CHO CO_2 + H_2O).

Oxygen and carbon dioxide transport in air and blood is by the process of convection. Their transport across biological membranes is by simple diffusion. They are transported in the blood in various forms because both gases are largely insoluble in the water which constitutes over 90% of blood plasma. Hence, almost all the oxygen that enters blood (97 – 98.5%) is transported in chemical combination with haemoglobin (Hb) as oxyhaemoglobin, while only 1.5 – 3% is dissolved in plasma. According to *Henry's law of solubility*, if the pressure of a gas over liquid increases, the amount of gas dissolved in the liquid will increase proportionally. On the other hand, as the gas pressure decreases, the amount of gas dissolved in the solution drops. Most of the carbon dioxide (60 – 70%) in the blood is converted to carbonic acid, which breaks down to the more soluble bicarbonate and hydrogen ions. Some of the carbon dioxide (20 – 30%) becomes chemically bound to Hb (carbaminohaemoglobin), while only 7 – 10% gets dissolved in plasma. Oxyhaemoglobin forms when an oxygen molecule reversibly attaches to a haeme portion of Hb. Carbaminohaemoglobin forms when a carbon dioxide molecule reversibly attaches to an amino portion of Hb. ***Chloride shift*****.** When erythrocytes move through tissue capillaries, they take in carbon dioxide and release bicarbonate ions. As bicarbonate ions are released, chloride ions (-1) shift into the erythrocytes in order to replace the negative bicarbonate ions (-1). The opposite of this occurs when erythrocytes move through pulmonary capillaries. This preserves charge balance in the erythrocytes.

Oxygenation of haemoglobin. One haemoglobin molecule has four binding sites for oxygen molecules: the iron (Fe^{2+}) atoms in the four haeme groups. Thus, each Hb molecule can bind four oxygen molecules. Haemoglobin changes shape based on the number of

oxygen molecules bound to it. The change in shape also alters its affinity to oxygen. As the number of oxygen molecules bound to haemoglobin increases, the affinity of haemoglobin for oxygen increases. This is known as *cooperativity*. Haemoglobin releases its bound oxygen in an acidic environment, as it is in the tissues where carbon dioxide is produced. In the tissue capillaries, oxygen bound to the haemoglobin is released into the blood's plasma and absorbed into the tissues.

The *Haldane effect* is a property of haemoglobin first described by John Scott Haldane, whereby oxygenation of blood in the lungs displaces carbon dioxide from haemoglobin, increasing the removal of carbon dioxide. Consequently, oxygenated blood has a reduced affinity for carbon dioxide.

Oxygen-haemoglobin dissociation curve. The curve (Figure 14) shows that haemoglobin is almost completely saturated when PO_2 is 80 mm Hg or above. At lower partial pressures, the Hb releases oxygen. Notable points on the curve include the p50, which is the pressure at which heamoglobin is 50% saturated (oxygen pressure of 27 mmHg on the X-axis); the arterial blood (oxygen pressure of 100 mmHg) where haemoglobin is approximately 100% saturated; and the venous blood (oxygen pressure of 40 mmHg) where haemoglobin is approximately 75% saturated with oxygen. A shift of the curve to the left results in an increase in the ability of haemoglobin to hold oxygen, while a right shift causes a decrease in

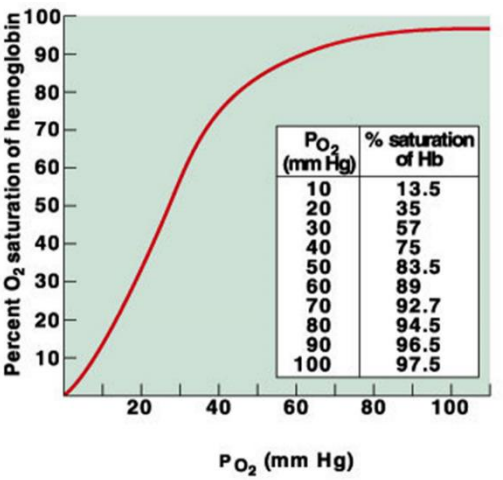


Figure 14: Oxygen-haemoglobin dissociation

the ability of haemoglobin to hold oxygen. Foetal haemoglobin has a higher affinity for oxygen than does maternal. When the carbon dioxide content of the blood increases, the resultant shift of the oxy-haemoglobin dissociation curve to the right is called the *Bohr effect*. Four reasons why oxy-haemoglobin is induced to give off oxygen in tissue capillaries (factors that cause a right shift in the oxy-haemoglobin dissociation curve and more oxygen unloading) include increases in carbon dioxide, body temperature, hydrogen ions (decreased pH) and 2,3-diphosphoglygerate (DPG). When bound to haemoglobin, DPG reduces the affinity of haemoglobin for oxygen. Elephant haemoglobin binds weakly, while ruminant haemoglobin in general is unresponsive to DPG.

Respiratory regulation of acid-base balance. The respiratory system adjusts pH using carbon dioxide; upon expiration, carbon dioxide is projected into the environment. Due to carbon dioxide forming carbonic acid in the body when combined with water, the amount of carbon dioxide expired can cause pH to increase or decrease. The respiratory centres contain chemoreceptors that detect pH levels in the blood and send signals to the respiratory centres of the brain to adjust the ventilation rate to change acidity by increasing or decreasing the removal of carbon dioxide (since carbon dioxide is linked to higher levels of hydrogen ions in the blood).

***Control/Regulation of Respiration*.** The primary respiratory centre that is responsible for the basic rhythm of breathing is located in the medulla. Two secondary respiratory centres (the pneumotaxic and apneustic respiratory centres) that serve to modify the rhythm of breathing are located in the pons. In addition, a panting centre is found in some species. Panting is a method of cooling, used by many mammals, most birds and some reptiles.

Factors that influence the respiratory centres include:

1. Higher brain centres (voluntary control over breathing via the cerebral cortex).
2. Stretch receptors in the lungs, muscles and joints.
3. Irritant receptors in the respiratory passage ways.
4. Chemoreceptors of the blood (aortic and carotid bodies) and cerebrospinal fluid (medullary).
5. Other receptors (e.g., pain) and emotional stimuli acting through the hypothalamus.

Summary

Blood is a connective tissue and medium for transportation (of respiratory gases, nutrients, metabolites), regulation (hormonal, temperature) and defence (protection, immunity). The circulatory system consists of the cardiovascular and lymphatic systems. It functions to circulate blood and lymph in the body. The main function of the lymphatic system is to provide immunological defences against pathogens, as it acts as a filter against microbes, organic waste, toxins and other debris. Respiration includes all the chemical and physical processes by which organisms exchange gases with their environment. The primary exchange is between oxygen and carbon dioxide. The oxygen that is delivered to cells is used as a substrate in combination with glucose to produce carbon dioxide and water. The respiratory system comprises all those organs and tissues that facilitate the uptake of oxygen from the air, its delivery to cells and the reverse expulsion of excess carbon dioxide from the body. The principal organ of the respiratory system is the lungs. Blood, circulatory and respiratory parameters provide useful diagnostic aids for the evaluation of the health status of animals, as they give an indication of events that are taking place in the remotest parts of the body.

Exercises

1. Why is blood essential to domestic animals?

2. List the functions of each of the plasma proteins and cellular components of the blood.
3. Write short notes on haematopoiesis, anaemia and polycythaemia.
4. Discuss the functions of the cardiovascular, lymphatic and respiratory systems.
5. Discuss each of the components/ phases of the electrocardiogram.
6. Write short notes on the heart valves, blood vessels, control of blood pressure and factors causing changes in blood pressure.
7. Distinguish between pulmonary ventilation, external, internal and cellular respiration using short definitions.
8. Explain or interpret the movement of gases between alveolar spaces, blood and cells due to differences in partial pressure.
9. Name the ways by which carbon dioxide and oxygen are transported by the blood.
10. Explain chloride shift for tissue and pulmonary capillaries.
11. Give four reasons why oxyhaemoglobin is induced to give off oxygen in tissue capillaries.
12. Give the location and function of the respiratory centres and list five factors that influence the centres.

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Chapter 5

VPY 202: Endocrinology, Renal and Digestive Systems

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Overview

Homeostasis explains the role of cells, tissues, and organs in the maintenance of stable conditions in the 'internal environment of animal. Therefore, in this chapter, the student is expected to understand the 'ways and means' or mechanisms by which endocrine hormones, the kidneys, and the digestive systems maintain a healthy condition in the body, by ensuring stable or constant conditions in the internal environment of the body of animals. The student is expected to know the different endocrine hormones/factors that regulate metabolism, reproduction, and growth through cell-to-cell communications, feedback mechanisms, and neuroendocrine controls; how the kidneys function to 'clean' the blood of unwanted byproducts of metabolism and excrete them in urine, regulate blood volume and composition, and acid-base balance; and how the digestive system ensures continuous supply of water and nutrients for utilization by the cells to produce the required energy to sustain metabolism. Ultimately, the student should be able to integrate the aforementioned knowledge to determine any deviation from normal body functions and how these deviations (due to disease) affect animal health, welfare, and productivity.

Objective

The objectives of this course are to:

1. express the physiologic effects of major endocrine organs and their hormones;
2. explain neuroendocrine control and feedback systems of hormone activity;
3. identify the effects of hormone hypo and hypersecretion and how it affects animal health and production;
4. explain the homeostatic functions of the kidneys – urine formation, maintenance of sodium, water, potassium balance, and calcium excretion; acid-base balance (bicarbonate excretion and acidification of urine); and
5. describe the distinctive features of gastrointestinal secretions, digestion, and absorption in monogastric, ruminant, and avian species.

Endocrine Physiology

Endocrine Glands

Endocrine glands secrete chemical messengers (*hormones)* that are taken by circulating blood to *target tissues/organs*, where they regulate body functions such as digestion, reproduction, growth, and development, among others. Based on the distance between the secretion site and the target cell, hormones can be categorized into *local* and *general /endocrine*. Local hormones are secreted into the surrounding interstitial fluid and act on the secreting cell or adjacent cells. They are also described as:

i) *paracrine* – secreted into surrounding interstitial fluid and acting on adjacent target cells *(*acetylcholine, histamine, and serotonin);

ii) *autocrine* – secreted into surrounding interstitial fluid and act on the same cells that produced them (e.g., mammary growth factor and nerve growth factor) and;

iii) *cytokines* – secreted into surrounding interstitial fluid but function as autocrine, paracrine, or endocrine hormones (e.g., interleukins and lymphokines).

On the other hand, *endocrine or general hormones* are transported through circulating blood to act on target cells at a distant location in the body (cortisol and insulin); and *neuroendocrine hormones* – are produced by neurons and released into circulating blood to act on target cells at a distant location in the body (e.g., oxytocin and anti-diuretic hormone).

Chemistry of Hormones, Transport, and Mechanisms of Action

Hormones can be categorized into three main classes based on the precursor chemical molecule from which they are synthesized. These include *amino acid derived* hormones (e.g., *thyroxine*)**;** *protein* or *peptide* hormones (e.g., *prolactin*)**;** and *lipid derived* hormones, including steroid hormones (*corticosteroids*); *autocoids* (histamine, serotonin, angiotensin, nitric oxide). Receptors for protein, peptide, and catecholamine hormones are found in or on cell membranes.

Water soluble or peptide hormones circulate freely in the blood and react with cell surface receptors to activate a transmembrane G protein which causes the formation of 3′ 5′ cyclic AMP (‘*second messenger*’) from cytoplasmic ATP. The second messenger 3′ 5′ cyclic AMP activates or inactivates specific enzymes which initiate a cascade of intracellular physiologic responses associated with the hormone action (Figure 1).

Lipid soluble thyroid and steroid hormones are transported bound to plasma proteins, ferried across the cell membrane by transmembrane proteins to bind to intracytoplasmic or nuclear receptors and activate or inactivate mRNA transcription, protein synthesis, and appropriate cell response. When hormone-receptor complex activity is high, the number of receptor proteins is depleted and tissue response to the hormone decreases subsequently (*downregulation*). On the other hand, some

hormones can induce the synthesis of more receptors (*upregulation*) and hence, cause increased tissue response to the hormone action.

The release of hormone is induced by local stimulus around the secreting cell (*humoral stimuli*), stimulation or inhibition by a specific regulatory hormone (*hormonal stimuli*), or by the action of neurotransmitters at synaptic junctions (*neural stimuli*).

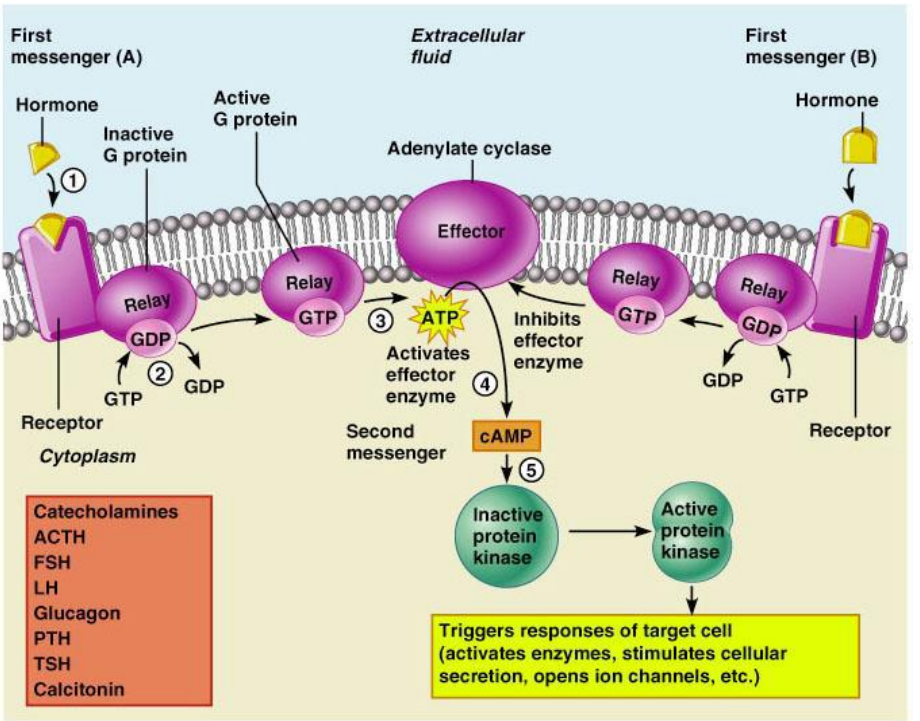

Figure 1: Mechanism of hormone action. Adapted from free online zoology notes on the general mechanisms of hormone action by **Nam Deuk Kim.** https://rnlkwc.ac.in/pdf/study-material/zoology/ZOO61.pdf.

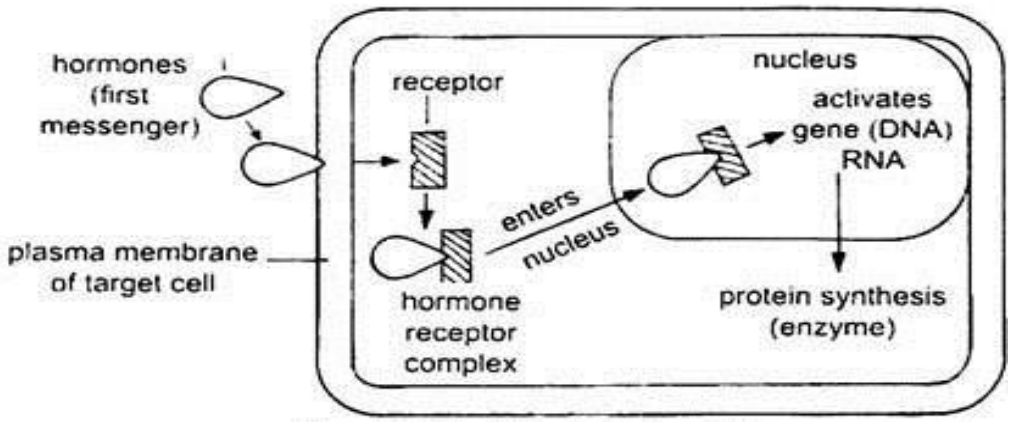

Figure 2: Action of steroid hormones. Adapted from free online zoology notes. https://www.notesonzoology.com/vertebrates/molecular-mechanism-of-hormone-action-with-diagram-chordata-zoology/8996.

Hypothalamus

The hypothalamus is the *control* or *integrative centre* for most nervous and endocrine functions of the body. It also acts as an endocrine organ that produces "releasing" or "inhibiting" hormones. These 'release' or 'inhibiting' hormones regulate the release of anterior pituitary hormones while exerting direct neural control on posterior pituitary hormones. The hypothalamus releases its hormones into the median eminence and the hormones are picked up and transported through a fenestrated capillary network called the *hypothalamic-hypophyseal portal system* to the secretory cells of the anterior pituitary namely: *corticotropes, gonadotropes, lactotropes, thyrotropes, and somatotropes*).

Hypothalamic and Pituitary Hormones

The hypothalamic "releasing" and "inhibiting" hormones and the anterior pituitary hormones they regulate, respectively include:

1. *Thyrotrophin-releasing hormone* (TRH) and *thyroid-stimulating hormone* (TSH).
2. *Corticotrophin releasing hormone* (CRH) and *adrenocorticotropic hormone* (ACTH).

3. *Growth hormone releasing hormone* (GHRH) and *growth hormone–inhibiting hormone* (GHIH) regulate growth hormone.
4. *Gonadotrophin-releasing hormone* (GnRH) regulates *follicle-stimulating hormone* **(**FSH) and *luteinizing hormone* **(**LH).
5. *Prolactin-inhibiting hormone* (dopamine) inhibits prolactin secretion.

The hormones of the anterior pituitary and the target tissue/organ they act on are as follows:

1. TSH acts on the thyroid gland to secrete thyroid hormones (T_4 and T_3).
2. ACTH acts on the adrenal cortex to secrete corticosteroids, aldosterone and androgens.
3. FSH promotes ovarian follicle development and oestrogen secretion, and sperm production. iv) LH induces the release of a mature egg from the ovary (*ovulation*), secretion of progesterone from *corpus luteum* and androgen from the testes.
4. *Prolactin* (PRL) acts on the mammary gland to induce growth, development, and milk production.
5. *Growth hormone* (GH) or *somatotrophin* acts on all cells of the body to cause cellular growth and division through the 'second messenger' effects of *somatomedins* or insulin - like growth factors (IGFs) produced from hepatocytes. The intermediate lobe of the pituitary gland (*pars intermedia*) secretes *melanocyte-stimulating hormone* (MSH) which stimulates melanin production by the skin melanocytes.

The posterior pituitary gland or neurohypophysis accommodates axon terminals coming from the supra-optic and paraventricular nuclei of the hypothalamus. The supraoptic nuclei (SON) produce mainly antidiuretic hormone (ADH), while the paraventricular nuclei produce oxytocin, which is both stored and released at axon terminals located in the posterior pituitary gland. The ADH promotes the retention of water in distal kidney tubules and increases blood pressure at higher concentrations. While oxytocin stimulates uterine contraction at

parturition and galactopoiesis and the 'milk letdown' reflex during lactation.

Thyroid and parathyroid glands

The thyroid follicular cells produce thyroxine (T4) and triiodothyronine (T3); whose primary function is the regulation of cellular metabolism (increased basal metabolic rate or BMR). In the blood, thyroid hormones are transported bound to thyroxine-binding globulins (about 80%), thyroxine-binding prealbumin (10 -15%), and albumin (5 – 10%). In target cells, thyroid hormones bind to mitochondria to increase the production of ATP (calorigenic effect), or to receptors in the nucleus to activate transcription of mRNAs and synthesis of proteins that regulate other aspects of energy metabolism. Other effects of thyroid hormones on body functions, include increased carbohydrate, protein, and fat metabolism, increased cardiac chrono–and inotropic effects, but with normal blood pressure, promote foetal growth and development, and increased secretory activity of other endocrine glands. The parafollicular or C cells of the thyroid gland secrete s calcitonin or thyrocalcitonin. Calcitonin lowers blood calcium concentration and is particularly important in bone remodelling during early life and pregnancy.

Parathyroid hormone (PTH) is secreted by the parathyroid part of the thyroid gland. It increases blood calcium levels. PTH is secreted in response to decreased blood calcium levels (hypocalcaemia). Thus, parathyroid hormone in synergy with calcitriol (Vitamin D), is the primary regulator of blood calcium level.

Table 1: Thyroid and Parathyroid Hormones, their Secreting Cells and Target Tissues/ Organs, Physiologic Effects, and Regulatory Hormone/Factors

Gland/Cells	Hormone	Target Organ/Tissues	Major Physiologic Effect	Major Regulatory Hormone/Factor
Thyroid gland (*Follicular cells*)	Thyroxine (T_4) Triiodothyronine (T_3)	Most cells of the body	Increase cellular metabolism, increase HR, and promotes foetal growth and development.	(+): TSH
C - cells	Calcitonin (CT)	Bone, Kidneys	Decrease Ca^{2+} concentration in blood.	(+): Elevated blood Ca_{2+} levels; (-): PTH
Parathyroid glands (*Principal cells*)	Parathyroid hormone (PTH)	Bone, kidneys	Increases Ca^{2+} level in blood.	(+): Low blood Ca_{2+} levels; (+): Calcitriol (-): calcitonin

(+): Stimulate secretion; (-): Inhibit secretion.

Adrenal glands

The adrenal (or *suprarenal*) glands are paired organs located on the superior pole of each kidney. Each gland is partitioned into two parts, an outer cortex and an inner medulla. The adrenal cortex produces

hormones that control carbohydrate, protein, and lipid metabolism *(cortisol*); electrolyte balance (*aldosterone*); hormonal (*cortisol*), and nervous (*adrenaline* – "flight or fight" reaction) responses to stress and anti-inflammatory effect. The adrenal cortex is further subdivided into three zones, namely:

i. *zona glomerulosa* - secretes a mineralocorticoid, *aldosterone*;
ii. *zona fasciculata* – secretes glucocorticoids: *cortisol*, *corticosterone*, *cortisone*, and
iii. *zona reticularis* - secretes androgens, mainly *testosterone*.

While the *adrenal medulla* produces *adrenaline* and *noradrenaline*.

Table 2: Hormones of the Adrenal gland, their Site of Secretion and Target Tissues/Organs, Physiologic Effects, and Regulatory Hormones/Factors

Adrenal Cortex	**Hormone**	**Target Organ/Tissue**	**Major Physiologic Effect**	**Major Regulatory Factor/Hormone**
Zona glomerulosa	Aldosterone	Kidneys	Increase blood Na^+ levels	(+): Angiotensin II, elevated blood K+, decreased plasma Na^+
Zona fasciculata	Glucocorticoids (cortisol, corticosterone, and cortisone	Most cells of the body	Increase blood glucose levels (gluconeogenesis), anti-inflammatory effect.	(+): ACTH
Zona reticularis	Androgens (Testosterone)	Most cells of the body	(+): Development of secondary sexual characteristics	(+): ACTH

Adrenal medulla	Epinephrine, Norepinephrine	Most cells of the body	Increase cardiac activity and blood pressure.	(+): Sympathetic preganglionic fibers

(+): Stimulate secretion; (-): Inhibit secretion; ACTH: Adrenocorticotrophic hormone.

Pancreas

The pancreas has both exocrine and endocrine functions. The cells of the *islets of Langerhans* perform the endocrine function and produce the hormones, insulin, and glucagon that control blood glucose level; *somatostatin* which inhibits gastrointestinal motility; and *pancreatic polypeptide* which controls digestive enzyme secretion and gall bladder activities. The cells of the *islets of Langerhans* and the hormones they secrete include *alpha cells* (*glucagon*), *beta cells* (*insulin*), *delta cells* (*somatostatin*); *pancreatic polypeptide cells* (*pancreatic polypeptide*).

Table 3: Hormones of the Pancreas, their Secreting Cell and Target Tissues/Organs, Physiologic Effects and Regulatory Hormones/Factors

Pancreatic Islets Cells	Hormone	Target Tissue/Organ	Major Physiologic Effect	Regulatory Control
Alpha (α) cells	Glucagon	Liver, adipose tissue	Increase blood glucose level	(+): Low blood level; (-): GHIH
Beta (β) cells	Insulin	Most cells of the body	Decrease blood glucose level	(+): High blood glucose level, (-): GHIH
Delta (δ) cells	Somatostatin (GHIH)	Alpha (α) and Beta (β) cells, digestive epithelium	Inhibits insulin and glucagon secretion, decreases GIT motility	(+): Protein-rich food
PP cells	Pancreatic polypeptide	GIT	(-): Contracts gall bladder; (+): Pancreatic enzymes and nutrient absorption.	(+): Protein-rich food, PSN.

(+): Stimulate secretion; (-): Inhibit secretion; GHIH: Growth hormone-inhibiting hormone; GIT: Gastrointestinal tract; PSN: Parasympathetic nervous system.

Thymus

The thymus gland produces a number of hormones known as **thymosins** that function to modulate cell migration, angiogenesis, and immune responses in young animals.

Endocrine Control and feedback mechanisms

Physiological control systems function to maintain homeostasis by stabilizing physiological parameters within the normal range around a set point. Hormones control bodily activities and maintain homeostasis through feedback control mechanisms. A *feedback mechanism* occurs when an action is regulated by sending information back to its initiator**.** Feedback mechanisms comprise *receptors* that sense stimuli (temperature, blood glucose or calcium level, etc.), and send signals to the *hypothalamus***,** which then relays appropriate messages to *effector organs*. These effector organs respond, either to up-regulate (increase) or down-regulate (decrease) the effect of the hormone on bodily functions. There are two main hormone feedback mechanisms, namely: *negative feedback mechanism*: which refers to a situation when a response diminishes the original stimulus. For example, high blood glucose following a meal stimulates insulin release from the pancreatic islets, which causes a decrease in blood glucose level and returns to normal. *Positive feedback:* occurs when the response enhances the original stimulus. For example, an increase in uterine contractions during parturition stretches the cervix, which causes increased oxytocin release from the posterior pituitary, resulting in more frequent and stronger contractions of the uterine muscle, until the baby is born.

Hypo-secretion and hyper-secretion of endocrine hormones

Abnormal endocrine secretion (hypo-or hyper-secretion) causes endocrine disorders. The most common endocrine disorders are caused by either: i) hormone overproduction or hypersecretion due to tumor or hyperplastic tissue, or ii) deficiency or hyposecretion, mainly due to autoimmune destruction of endocrine tissue. The commonest endocrine disorders associated with endocrine hypersecretion in domestic animals are hyperthyroidism (cats) and hyperadrenocorticism or Cushing's

disease (dogs), while common disorders of endocrine hypo-secretion or hypo-function, include: hypothyroidism (dogs), type 1 diabetes (dogs and cats), and primary hypoadrenocorticism (Addison's disease; dogs).

Renal Physiology

The Kidney and its Functions

The primary components of the renal or urinary system in mammals are paired kidneys and ureters, bladder and urethra. Primarily, the kidneys function to 'clean' blood plasma of unwanted byproducts of protein and muscle metabolism: urea, uric acid, urates, creatinine; end products of haemoglobin metabolism (bilirubin), hormone metabolites, foreign chemicals, drugs, and other toxic substances. They perform this function by filtering the plasma of unwanted substances, then excreting them through urine and retaining substances required for normal body activities. The kidneys also regulate blood chemicals and electrolyte concentrations, extracellular fluid osmotic pressure (osmolarity), arterial blood pressure, and acid-base balance. Furthermore, the kidneys also secrete erythropoietin and perform gluconeogenesis. In the event of kidney disease, these kidney functions are significantly compromised requiring clinical intervention like *haemodialysis* in extreme situations.

The Nephron

The nephron is the functional unit of the kidney. Each kidney contains a million or so nephrons (approximately 415,000 in dogs; 4,000,000 in cattle). Each nephron is able to form urine. The nephron is comprised of a specialized capillary network (*glomerulus***)** that filters blood plasma to produce a *glomerular filtrate* and a *tubular system* that converts the glomerular filtrate into urine. Each glomerular capillary network is encased in a layer of epithelial cells called *Bowman's capsule*. The kidney nephrons are classified as either *cortical and Juxtamedullary nephrons.* The glomeruli of cortical nephrons are found in the outer cortex and short loops of Henle, while the glomeruli of Juxtamedullary

nephrons are situated in the inner cortex with their loops of Henle extending into the inner medulla. A portion of the efferent arterioles of juxtamedullary nephrons extends into the inner medulla as a special capillary network (*vasa recta)* which runs alongside the loop of Henle.

Urine formation

The kidneys employ three basic processes to form urine, namely: *glomerular ultrafiltration*, *tubular secretion,* and *tubular reabsorption.*

Glomerular Ultrafiltration

The first step in urine formation is the filtration of a large quantity of protein-free glomerular filtrate or ultrafiltrate from the plasma across the glomerular capillary membrane to the lumen of Bowman's capsule. The glomerular capillary membrane is selectively permeable to water, salts, and other electrolytes and plasma constituents, except proteins and cellular elements, including red blood cells. Thus, glomerular ultrafiltrate contains all other components of plasma, except plasma proteins.

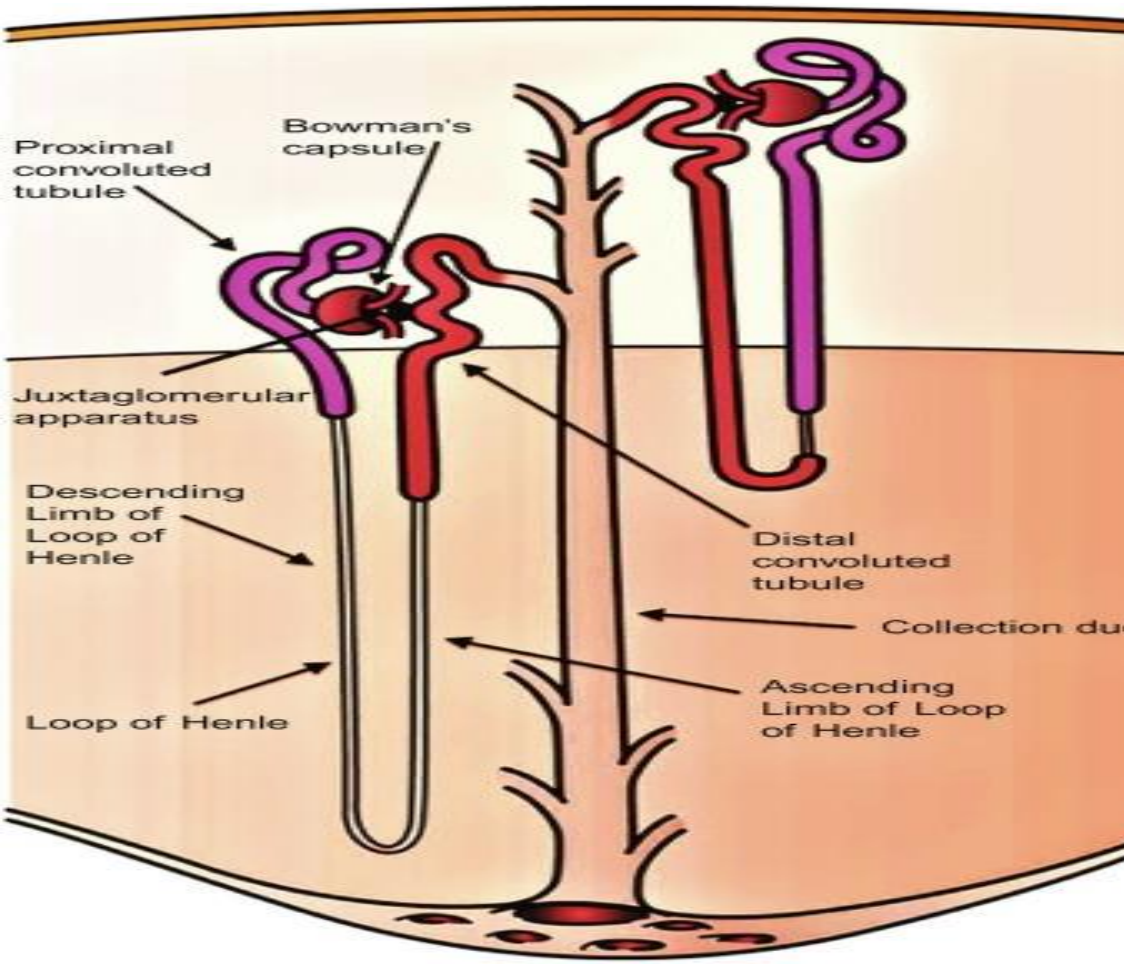

Figure 3. A diagrammatic representation of different segments of a kidney nephron. Adapted from Shankhajit De and Ryuichi Nishinakamura (2022). Advances in Stem Cell Biology, Pages 201-213.

Tubular Reabsorption

The primary function of the kidney tubular system is reabsorption (Figure 3). Reabsorption of water, salts, and other electrolytes is

mandatory in the proximal tubules (60%); in the loop of Henle, it depends on the amount of salt and water in the blood (32%); while the balance of 8% reabsorption occurs in the distal tubules and collecting ducts depending on the needs of the body (*optional*). Depending on the nephron segment, materials are transported across the tubular epithelium through primary or secondary active transport, facilitated diffusion, or co-transport with a carrier protein or by simple diffusion. Water, sodium, chloride, potassium, and bicarbonate ions are avidly reabsorbed in all nephron segments (minimally excreted); urea, creatinine, and uric acid are minimally reabsorbed (maximally excreted); while glucose, amino acids, and vitamins are completely reabsorbed (none excreted). The substances that are secreted include hydrogen ions (proximal and distal tubules) and potassium ions (in exchange for sodium reabsorption in the distal tubules). The hormones that regulate renal tubular functions include *angiotensin II* (causes Na^+ and H_2O retention and H^+ secretion); *antidiuretic hormone* (ADH; promote H_2O retention); *aldosterone* (causes Na^+ retention and K^+ secretion in the early and late distal tubules).

Glomerular filtration Rate

The glomerular filtration rate (GFR) refers to the volume of glomerular ultrafiltrate produced from both kidneys per minute. It is determined experimentally, by measuring the '*plasma clearance*' of *inulin*. *Plasma clearance* is the volume of a substance that is removed or 'cleared' from the plasma by the kidneys in unit time. Thus, $GFR = Uin \times V/Pin = Cin$; where: *Uin* – quantity of inulin in urine; *Pin* – quantity of inulin in plasma; *V*- quantity of urine excreted in unit time; *Cin* - plasma clearance of inulin. The glomerular filtration rate can also be expressed as: $GFR = K_f \times Net\ filtration\ pressure$, where K_f is the coefficient of glomerular filtration. The GFR averages 125 mL/min in an adult man (37 mL/min/10kg beagle dog). Factors that can affect GFR include hydrostatic and colloid osmotic pressures in the glomerular membrane, *adrenaline*, *noradrenaline* (decrease GFR), *prostaglandins* (increase

GFR), and sympathetic stimulation (decrease GFR). Local feedback mechanisms within the kidney (*autoregulation*) help to maintain constant GFR despite arterial pressure changes. This autoregulation functions to prevent extreme changes in renal excretion of salts and water and ensure precise control of blood volume and composition.

Autoregulation of Glomerular Filtration Rate

The autoregulation of GFR is accomplished mainly through the *tubuloglomerular feedback* mechanism, which depends on a special physio-anatomic feature of the *juxtaglomerular complex or apparatus*. The *juxtaglomerular apparatus* has *macula densa* cells (early distal tubule) that sense sodium concentration and *juxtaglomerular cells* (afferent and efferent arterioles). The two components of the mechanism are the *afferent arteriolar vasodilator* mechanism and the *efferent arteriolar vasoconstrictor* mechanism. In the event of decreased renal perfusion and GFR, a lower quantity of sodium chloride reaches the *macula densa* cells. Low sodium chloride concentration at the level of *macula densa* cells causes two effects: i) afferent arteriolar vasodilation, and ii) release of *renin* (from *juxtaglomerular cells*) which assists the formation of angiotensin I; conversion of Angiotensin I to Angiotensin II (in the lungs) which then causes vasoconstriction of the efferent arterioles. Thus, the two mechanisms ensure that GRF changes only minimally, despite large fluctuations in arterial pressure. Another mechanism used by the body to control GFR and systemic arterial pressure in a common feedback loop is the *renin-angiotensin-aldosterone* mechanism. Additionally, the *myogenic reflex,* an intrinsic mechanism that relies on the inherent resistance of the renal capillary system to increase arterial pressure, also assists in the autoregulation of GFR.

Renal Excretion of Water and Sodium

For cellular metabolic activity in the body to proceed efficiently, the osmotic pressure (osmolarity) in the ECF (blood) must be kept constant. The osmolarity of the ECF is determined primarily by the ratio of body water to sodium concentration. The quantity of body water is controlled

through fluid intake and excretion by the kidneys. Thus, the kidneys regulate total body water and sodium through i) losing excess water and retaining salts (mainly NaCl) and excreting dilute urine; or ii) conserving water but losing excess salts and excreting concentrated urine. The primary signal that determines whether the kidneys produce dilute or concentrated urine is ADH. Thus, the prerequisites to produce concentrated urine by the kidneys, include i) a high level of circulating ADH, and ii) a hyperosmotic inner medullary interstitium which promotes movement of water from collecting ducts to the interstitium. The mechanism employed by the kidneys to create and enhance hyperosmolarity in the renal medullary interstitial fluid is called *Countercurrent 'multplier' mechanism* of the loop of Henle. Furthermore, to sustain the renal medullary hyperosmolarity, the kidneys employ another mechanism, called the *Countercurrent 'exchanger' mechanism of the vasa recta*, which prevents the depletion of solutes from the inner medullary interstitial fluid during the production of concentrated urine.

The signal for the kidneys to excrete dilute or concentrated urine is triggered by a neuroendocrine mechanism called the *Osmoreceptor–ADH feedback system.* This feedback system when triggered responds as follows: increased ECF sodium concentration (high osmolarity) or water deficit (dehydration) stimulates osmoreceptor cells near the supraoptic nuclei (SON) in the anterior hypothalamus; the neurons of the SON send appropriate signals that cause ADH release from the neurohypophysis. Thereafter, the ADH is transported through the blood stream to distal kidney tubules where it promotes the reabsorption of water. The *Osmoreceptor-ADH feedback system* ensures that water is retained to dilute the ECF, while excess sodium is lost in urine. However, in the event of decreased sodium concentration (low osmolarity), an opposite sequence of events is triggered. Other factors that stimulate ADH secretion include decreased blood volume, lowered blood pressure, nausea, nicotine, etc.

Renal Excretion of Potassium and Calcium

The maintenance of ECF potassium concentration within the normal range is very important for many cellular functions (nerve conduction, muscle contraction, etc.). When blood potassium concentration is higher than normal, the *principal cells* of the late distal tubule secrete potassium. Thus, high plasma potassium concentration and *aldosterone* are the primary determinants of potassium excretion by the kidneys. Whereas renal excretion of calcium is principally determined by PTH. Low blood calcium stimulates PTH-induced calcium reabsorption in distal tubules of the kidney nephron resulting in decreased urinary calcium excretion. In addition, increased plasma phosphate stimulates PTH, hence causing calcium reabsorption and reducing calcium excretion. Renal calcium excretion is also affected by metabolic acidosis, metabolic alkalosis, and Vitamin D_3.

Acid-Base Balance (pH) and Urine Acidification

The range of pH of body fluids is 7.35 (interstitial fluid) to 7.4 (blood). Reduced pH or elevated hydrogen ion concentration is called *acidemia* or *acidosis*, while increased pH or reduced hydrogen ion concentration is called *alkalemia* or *alkalosis*. The kidneys ensure stable blood pH by excreting acidic or basic urine. Cellular metabolism results in the formation of water, carbon dioxide, and urea. In blood plasma, carbon dioxide reacts with water to give carbonic acid as follows: $CO_2 + H_20 \leftarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$. The kidneys help to maintain a constant pH in body fluids by i) reabsorption of bicarbonate (HCO_3^-), ii) excretion of hydrogen ions (H^+), and iii) formation of ammonia (urinary buffer). Thus, by careful adjustment of HCO_3^- and H^+, the kidneys regulate acid-base balance and prevent the development of acidosis or alkalosis. The diet also influences urine pH with carnivores and omnivores excreting acidic urine, while herbivores excrete alkaline urine.

Micturition

Micturition (urination) is the emptying of the urinary bladder. It is a spinal cord reflex initiated by spontaneous contractions of the bladder when it is filled with urine. It is facilitated or inhibited by higher brain

centers. Micturition is usually under voluntary control. When this control is lost or absent, urine flows uncontrollably (*urinary incontinence*).

Digestive Physiology

Monogastric Digestion

Monogastric animals possess a single compartment stomach (dog, cat, pig, human). The homeostatic function of the *alimentary* or gastrointestinal *tract* (GIT) is to provide the body with a regular supply of water, nutrients, vital electrolytes, and minerals to sustain growth and development. Thus, the main functions of the GIT and its accessory glandular organs are digestion and absorption of nutrients and excretion of waste by-products of digestion. The GIT carries out these functions by allowing the movement of food along the GIT; secretion of digestive enzymes and bile, digestion and absorption of nutrients, water, and various electrolytes; elimination of waste products; and the nervous and hormonal control of these processes. The monogastric alimentary tract is tube-like and comprised of the mouth, pharynx, esophagus, stomach, small intestine, large intestine, and anus. The accessory glandular organs are comprised of the salivary glands, liver, and pancreas. Digestion (breakdown of food) is accomplished through three processes, namely:

i) *prehension* (taking up of food), *mastication* and *swallowing* in the mouth,

ii) hydrolysis or *enzymatic digestion* in the mouth, stomach and small intestine, and

iii) *absorption* of nutrients in the jejunum and large intestine (colon).

Gastrointestinal Motility

There are two types of GIT motility: i) propulsive movements, that push food along the GI tract to facilitate digestion and absorption, and ii) mixing contractions, that ensure intestinal contents are properly mixed for enzymatic action. Gastrointestinal motility has both neural (*myenteric reflex*) and hormonal control (*gastrin*, *secretin*, *cholecystokinin*). The types of small intestinal motility are:

i) propulsive wave-like (*peristaltic reflex*) that propels ingesta for a short distance, and
ii) non-propulsive (*segmentation movement*) that mixes gut contents with digestive juice over the absorptive mucosal surface.

The main functions of the large intestine, include:
i) absorption of water and electrolytes from intestinal contents, and
ii) formation and storage of faeces until *defecation* occurs.

The two types of large intestinal movements are:
i) *haustrations* or mixing movements, and
ii) *mass* or propulsive movements that push faeces to the rectum and initiate *defaecation reflex*.

Secretory Functions of the Gastrointestinal Tract
The entire alimentary tract is lined with glands whose primary function is to secrete *digestive enzymes* and *mucus* (for lubrication and protection of the alimentary tract). The type and quantity of digestive secretion are influenced by the presence and type of food. Secretory glands in the alimentary tract, include:
i) mucus or *goblet cells* (stomach),
ii) tubular *parietal* or *oxyntic glands* (stomach),
iii) pits or *crypts of Lieberkuhn* (small intestine),
iv) salivary glands, pancreas, and liver (gall bladder – stores bile for fats emulsification).

Saliva: the saliva functions in all mammalian species to facilitate mastication and deglutition. In dogs and cats, saliva has an additional thermoregulatory role. The components of saliva include lysozyme, mucin, and salivary amylase (rats and pigs).
Gastric secretion: is composed of water, hydrochloric acid (HCl), mucus, and pepsinogen, and is secreted in three phases, namely: *cephalic phase* **-** activated by thought, aroma, and sight of food, and

swallowing, ii) *gastric phase* - activated by the presence of food in the stomach and gastric distension, and iii) *intestinal phase* **–** stimulated by-products of protein digestion in the duodenum. Hormones that control gastric secretion include, *gastrin* (stimulate HCl secretion, gastric motility and relaxes pyloric sphincter), *histamine* (stimulates HCl secretion), prostaglandins (inhibit histamine and acid secretion, stimulate mucus production).

Pancreatic Secretion*:* exocrine pancreas secretes trypsinogen and chymotrypsinogen as inactive *zymogens* into the duodenum. They are activated to trypsin and chymotrypsin by *enterokinase* produced in the small intestine. Like gastric secretion, pancreatic secretions occur in cephalic, gastric, and intestinal phases with the cephalic phase representing about one-third of the response to a meal in dogs. Hormones that regulate intestinal secretion, include *cholecystokinin* (stimulates the secretion of pancreatic enzymes and bile, gall bladder contraction); *secretin* (stimulate alkaline secretion from the saliva, pancreas, and intestine).

Bile Secretion: bile is synthesized by the hepatocytes as bile salts and functions in i) *emulsification of fat* -breaking large fat droplets in food into many tiny particles to aid hydrolysis by pancreatic lipase, ii) absorption of digested fat (formation of *micelles*), and iii) excretion of water and insoluble waste products, bilirubin, and cholesterol. Bile is composed of bile acids (cholic and chenodeoxycholic acid) produced from cholesterol. These acids combine with taurine and glycine to form *glyco* -and *tauro* – acids which are secreted as sodium salts in bile. The bile acids and salts are transported through hepatic portal veins, where the bile salts are taken up by the hepatocytes and then re-secreted. This process is termed *enterohepatic bile circulation.*

Digestion

Digestion is the process of chemical 'break down' or hydrolysis of carbohydrates, proteins, and fat taken in food into simple absorbable molecules. The primary site of digestion and absorption is the jejunum of the small intestine. Digestion occurs in two phases in the small

intestine, namely: *luminal* and *mucosal* phases. *Carbohydrate digestion:* begins in the oral cavity through the hydrolytic action of *salivary α-amylase* (pH: 6.0 – 7.0) and continues at the duodenum through the effects of *pancreatic amylase*. These enzymes hydrolyse complex starches to disaccharides, maltose, isomaltose, lactose, and sucrose, which are further hydrolysed to their respective monomers (glucose, galactose, and fructose) by intestinal *maltase* and *isomaltase*, *lactase*, and *sucrase*, respectively. *Protein digestion*: commences at the stomach by the hydrolytic effect of pepsin (pH 1.3 – 3.0 provided by gastric HCl) to produce amino acids and dipeptides. The intestinal (luminal) phase of protein digestion utilizes trypsin, chymotrypsin, elastases (endopeptidases), and carboxypeptidase A and carboxypeptidase B (exopeptidases) to yield amino acids. Gastric HCl helps protein digestion by breaking down protein connective tissues and converting pepsinogen to pepsin. Protein digestion is finalized by the brush border enzymes (*dipeptidases* and *tripeptidases*) to release free amino acids within the enterocytes and enterocyte surface. *Fat digestion:* lipid digestion is accomplished sequentially by emulsification, hydrolysis, *micelle* formation, and absorption. Pancreatic lipase, phospholipase, and cholesterol esterase hydrolyse triglycerides (as *micelles)* to monoglycerides and free non-esterified fatty acids.

Absorption

Absorption is defined as the movement of digestive end-products across the jejunal mucosa into the vascular system for distribution to the liver and other organs. Products of *protein digestive activity* such as tripeptides, dipeptides, and amino acids are transported across the luminal epithelium of the enterocytes by *sodium dependent* or *facilitated diffusion, simple diffusion,* or *endocytosis*. *Fat absorption* occurs mainly in the duodenum by the transportation of *micelles* across the brush border of the enterocytes. The micelles diffuse passively across the enterocytes to the interior of the cell leaving behind bile salts in the gut lumen. Once inside the enterocytes, the lipids are again encased in water-soluble lipoproteins called *chylomicrons* and transported through the central lacteal to the liver and peripheral

tissues. *Carbohydrates absorption* occurs in the small intestine as monosaccharides (*glucose*, *galactose,* and *fructose*). Absorption of glucose and galactose occurs by sodium-dependent active transport, fructose through facilitated diffusion, and pentoses by simple diffusion.

Ruminant Digestive Physiology

The digestive process in ruminants occur stepwise in four-chambered stomach compartments. The diet of herbivores is largely comprised of fibrous materials such as hay, silages, straw, cereals, and others. The alimentary tract of the ruminant is anatomically suited for fermentation, to handle digestion of *cellulose*. Digestive enzymes produced by ruminant animals are incapable of handling cellulose. Therefore, ruminant animals rely on *microbial fermentation* and the *volatile fatty acids* (VFAs) derived from it to generate ATP required to drive cellular metabolic processes.

Ruminant Alimentary Tract

The alimentary canal of the ruminant is made up of the mouth (oral cavity) and oesophagus, and a four chambered stomach compartment namely: the *rumen*, *reticulum*, *omasum,* and *abomasum* (glandular stomach).

*Mouth***:** the ruminant tongue is used for the prehension of food. Ruminants produce copious amount of saliva, which lubricates the GIT, aids bolus formation and swallowing in the mouth and oesophagus as well as buffer the pH of the rumen and reticulum. A mature cow produces about 200 L of saliva per day. The saliva in ruminants is isotonic but has a high concentration of phosphate and urea.

Oesophagus: the muscular oesophageal tube connects the pharynx with the rumen and functions bi-directionally in ruminants allowing regurgitation of swallowed ingesta. *Rumination* ('chewing the cud') is the regurgitation, re-mastication, re-in salivation, and re-deglutition of already ingested herbage. The re-swallowed cud passes into the *reticulum***.** The solid portion is layered and settled in the rumen, while the liquid portion in the *reticulorumen* is propelled into the *omasum* and later into the *abomasum.* The ingesta remains in the rumen for 48 hours

to allow proper fermentation by ruminal microbes (up to 20 different species of bacteria, protozoa, and fungi). These microbes extracellularly digest the food substance to form volatile fatty acids (*VFAs*) which serve as energy substrates for ATP production in the host animal.

Rumen: is the first and largest compartment of ruminants' stomach and is referred to as the *fermentation chamber*. It has an extensive surface area for absorption of VFAs. About 60% of starch is digested in the rumen. Rumen microflora, especially the bacteria digests plant cellulose and synthetizes protein from non-protein nitrogen. The rumen environment is anaerobic, and its pH is typically between 6.5 and 6.8. The major VFAs produced in the rumen because of microbial digestion are propionic acid, butyric acid, and acetic acid. In addition, methane, carbon dioxide, ammonia, and hydrogen sulphide are also produced in the rumen. Contractile activity of the rumen aid in the expulsion of these gases through *eructation ('belching')*. Rumen atony often leads to *tympani (bloat*) in ruminants.

Reticulum: is the second forestomach and has a honeycomb appearance. Its main function is to transfer smaller particles of ingesta from the rumen into the omasum while retaining the denser materials in the rumen. Immature ruminants have an *oesophageal groove* that channels (*bypasses)* milk to the reticulum (*oesophageal reflex*) to prevent its destruction by rumen microbes.

Omasum: is the third forestomach and receives the liquid portion of the ingesta after fermentation in the rumen-reticulum. Its inner surface is lined with long leave-like flaps that also absorb VFAs and water.

Abomasum: is the fourth and last compartment of the ruminant stomach and is also known as the `*true stomach*'. As in monogastric animals, the abomasum operates at acidic pH (2.0 - 3.0) and produces hydrochloric acid and pepsinogen for protein digestion.

Small intestine: is the site of digestion and absorption of the ingesta coming from the abomasum. They receive both pancreatic enzymes and bile needed for lipid digestion. Structurally, the small intestine is equipped with numerous villi that aid the process of absorption.

Large intestine: the caecum, colon, and rectum are the main components of the large intestine in ruminants. It functions to absorb

water and electrolytes and for storage of faeces. The colon in non-ruminant herbivores such as horses is well developed and is the site of fermentative digestion. The motility pattern in the colon involves *peristalsis, antiperistalsis,* and *segmentation* movements. The purpose of these movements is to retain the ingesta for a reasonable period of time needed for absorption.

Avian Digestion

The digestive tract of domestic birds is modified to suit their feeding habit. The beak is responsible for *prehension*, while the *oropharynx* is the combined oral cavity (mouth and pharynx) that links the mouth to the oesophagus. There is no epiglottis guarding the glottis. During swallowing (oral, pharyngeal, and oesophageal phases), the triangular tongue molds the bolus of food in the oropharynx, propelling it into the oesophagus. There is a well–developed salivary gland (chicken and turkeys), but little *amylase*. The saliva functions to moisten ingested food and provide lubrication for swallowing.

Gastrointestinal Tract

At the thoracic inlet of the avian oesophgus is a dilatation, called *crop* (ingluvies) that serves as a food storage depot. In the thoracic region, the post-crop oesophagus terminates in the *proventriculus*. The oesophagus produces abundant mucus for lubrication during swallowing. The stomach is two-chambered, *proventriculus* (glandular stomach) and *ventriculus* or *gizzard* (muscular stomach). The mucosal surface of the gizzard is lined with a thick cuticle (*koilin*), which protects the gizzard from acid and proteolytic enzyme action. Small stones (*grit*) present in the gizzard are used for grinding hard food by the thick muscles of the gizzard. Grit is regularly ingested, but if absent, food stays longer in the gizzard.

Small intestine: continues caudally from the ventriculus, as the duodenum, jejunum, and ileum with indistinct borders. The *Meckel's diverticulum* (vestigial yolk sac) is located midway between the jejunum and ileum. The ileum ends with a valve at the *ileocaecocolic* junction.

Large intestine: comprises of twin caeca and *colon*. Little or no digestion takes place in the caeca. The avian caeca function to reabsorb water from refluxed urine and for microbial digestion of cellulose.
*Rectum and cloaca***:** the rectum (colon) is short and links the ileum with the cloaca. The cloaca has three compartments, namely: *coprodeum, urodeum, and proctodeum*. The coprodeum collects faecal matter from the colon, the urodeum empties the genitourinary tracts, while the proctodeum opens into the *vent* or anus. The ***Bursa of Fabricius*** (cloacal bursa) projects dorsally from the proctodeum.
Liver and *pancreas*: a bi-lobed liver, pancreas, and gall bladder are present (chickens, turkeys, ducks, and geese).

Gastrointestinal Motility
There is a rhythmic *gastroduodenal contraction* sequence (chickens, turkeys), occurring at three contractions per minute that pushes ingesta *aborally* into the duodenum. In turkeys, there is duodenal and upper jejunal reflux of chyme into the ventriculus that permits remixing of intestinal content with gastric secretions. *Peristalsis, antiperistalsis,* and *segmentation* contractions occur in the ileum. The antiperistalsis functions to i) move urine from the cloaca into the colon and caeca for reabsorption of water, and ii) fill the caeca with ingesta. Antiperistalsis ceases just before defecation to allow the colon to contract and evacuate faeces. *Caecal droppings* (1-2 per day) are chocolate-brown with a homogenous texture, while *intestinal droppings* (25 - 50 per day) are greenish and granular–textured.

Gastrointestinal Tract Secretions and Digestion
Significant digestion of starch occurs in the crop due to bacterial action. Non-bacterial digestion of carbohydrates also occurs in the crop due to amylase reflux from the intestine. The proventriculus secretes mucus, HCl, and pepsinogen. The grinding action of the gizzard reduces food particle size and mixes the ingesta with digestive fluids. The small intestine serves as the site of chemical digestion by pancreatic enzymes and microbes, as well as intestinal secretions. The exocrine pancreas secretes lipase, amylase, trypsinogen (activated by *enterokinase* to

trypsin), chymotrypsinogen A, B, and C (chymotrypsins) and procarboxypeptidase A and B (carboxypeptidases). Trypsin and chymotrypsins hydrolyse polypeptides to oligopeptides, intestinal carboxypeptidases release free amino acids from oligopeptides, while *aminopeptidases* and *dipeptidases* hydrolyse oligopeptides. Amylose and amylopectin are hydrolysed to maltose by pancreatic amylase, while *maltase*, *isomaltase* and *sucrase* are the main carbohydrate splitting enzymes in the intestine. Lipids are hydrolysed to fatty acids, phospholipids, and glycerol through the action of *pancreatic lipase*, while bile salts emulsify fats and activate pancreatic lipase. Hormonal factors that control avian gastrointestinal secretions include *Gastrin*, *gastrin releasing peptide* (GRP), *cholecystokinin* (CCK), and *vasoactive intestinal peptide* (VIP).

Absorption

Absorption of nutrients in the avian gut occurs principally in the duodenum and early jejunum (glucose, amino acids), late jejunum, and ileum (fatty acids). Fatty acids are protein-enveloped into *portomicrons* before being absorbed directly into the hepatic portal blood vein (birds lack central lacteal). Microbial decomposition of urine in the caeca produces VFAs (acetate, propionate, and butyrate) that are absorbed by the ileum and caeca. Absorption of water and electrolytes occurs in the late jejunum.

Urine is refluxed from the urodium into the coprodeum, and then the colon and caeca via *antiperistalsis*. Urine mixed with faeces and water may be absorbed from the colon and caeca to maintain osmotic equilibrium in the ECF. The energy needs of avian embryos during incubation are met by lipids stored in the *yolk sac*. The lipids are converted to lipoproteins, endocytosed by the yolk sac cells, and released into the blood stream. In addition, yolk content is also secreted through the *yolk stalk* into the intestine.

Summary

Location of different types of endocrine glands in the body, the hormones/factors they produce, the chemical nature of the hormones

and their mechanisms of action were discussed. Also, the role of the hypothalamus and pituitary gland in the general and specific control of most endocrine glands, their secretory activity and the clinical implications of hypo- or hypersecretion of some endocrine glands as well as its effects on the health and productivity of domestic animals are covered. The different organs and processes involved in the physical and chemical breakdown of food in the gastrointestinal tract of monogastric, ruminant, and avian domestic animal species are discussed. The mechanisms employed by the gastrointestinal tract in the secretion of digestive enzymes and absorption of digestive nutrients for utilization by the body are explained. Furthermore, the course highlights the peculiarities of digestive processes in monogastric, ruminant, and avian domestic species. In addition, the role of the kidneys in homeostatic control of bodily functions, and the physio-anatomic features of the kidney nephron that enables it to carry out basic processes of urine formation and excretion of water, salt, and other electrolytes are explained. The course also discusses the role of hormones, systemic arterial pressure, renal vascular perfusion, and the kidney itself in the regulation of its excretory functions.

Exercises

1. List any five hormones of the hypothalamus and the anterior pituitary hormone each of them regulates.
2. List any five anterior pituitary hormones and one major physiological effect of each.
3. Mention three important physiologic effects of thyroid hormones.
4. List any two hormones each, secreted from the adrenal cortex and medulla, and mention one physiologic effect of each of the hormones.
5. List the four cell types of pancreatic Islets and mention one hormone produced by each cell type and its main physiologic effect.
6. List any five important functions of the kidney.

7. List the three processes employed by kidney nephrons for urine formation.
8. Define GFR and list any three factors that affect GFR.
9. Explain the autoregulation of GFR.
10. Mention any three hormones and their effect on kidney function.
11. List any three functions of the saliva in monogastric digestion.
12. List any three GIT hormones and one function for each, in monogastric digestion.
13. Mention any three types of gastrointestinal motility and their role in monogastric digestion.
14. List the compartments of the ruminant forestomach and the digestive function of each.
15. Describe briefly any three distinct features of avian digestion.

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Chapter 6

VPY 204: Veterinary Physiology III (Central and Autonomic Nervous System, Special Senses and Muscle)

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Overview

This course examines the physiology of excitable tissues, which comprises cells that can generate and or transmitting electrical signals in the form of action potential induced by depolarisation of the membrane and change in the membrane potential between the intracellular and extracellular matrices. These excitable cells include the various types of neurones and receptors, skeletal, smooth, and cardiac muscles. Meanwhile, our attentions shall be focused on the nervous and skeletal muscle tissues in this chapter.

Objectives

The objectives of this course are to:

1. describe the homeostatic role of the nervous system;
2. explain nerve cell communication;
3. outline the nervous system structures, divisions, and their roles;
4. describe how the brain and the spinal cord are protected and nourished;
5. distinguish between the parasympathetic and sympathetic nervous systems;
6. identify the special senses, their structure, and functions;

7. relate types of sensory receptors to their function and the nervous pathways to the central nervous system; and
8. describe the different types of muscles and explain the functions of each.

The Nervous System

The components of the nervous system are the brain, spinal cord, and a neuronal network. The system sends, receives and interprets information from every part of the body. It coordinates the functions of body organs and adjusts to changes in the environment. This system comprises two parts: The central nervous system and peripheral nervous system. In animals, the integration and coordination of information relayed from all body parts occur in the central nervous system. The central nervous system is the centre for processing of information received and its transmission to the peripheral nervous system. The brain and the spinal cord are the two major structures of the central nervous system. The peripheral nervous system is made up of the somatic and autonomic nervous system. The somatic (or animal) nervous system is the relays information that is voluntary both to and from skeletal muscle. The autonomic (automatic, vegetative) nervous system is a motor system that controls involuntary activities originating from the glands, smooth and cardiac muscles. It has three subdivisions: (i). Sympathetic nervous system – participates in body's response to stress; fright, fight, and flight (3fs) reaction; (ii) Parasympathetic nervous system – returns body to resting state and conserves resources. Both systems exert opposite actions, though, not in all cases; and (iii). Enteric nervous system – controls smooth muscles of the gut. The nervous tissue comprises neurones (nerve cells) and neuroglia.

The neuroglial cells directly surround the nerve cells in the spinal cord and brain. They include microglia, which constitute the major macrophages in the nervous system. Neurones are basic morphologic and functional unit of the nervous system. A neurone has four distinct parts: the cell body (or soma), axons, dendrites, and axon terminals.

Neurones can be grouped in two ways based on their: (i). Structures (anaxonic, unipolar, bipolar, and multipolar neurones); and (ii). Functions (sensory neurones, interneurones, and motor neurones). The neuroglial cells, which are the non-neuronal cells of nervous system, ensure metabolic support for neurones. The neuroglial cells are: (i). Astrocytes, which regulate the chemical micro-environment surrounding neurones are involved in metabolism and response to brain injury; (ii). Oligodendrocytes. These cells form myelin in brain and spinal cord; (iii). Ependymal cells. These are columnar cells that line the ventricles where they form the choroid plexuses; and (iv). Microglia, which are phagocytic cellsthat are capable of migration, and are similar in function to the immune cells that eliminate debris, waste products and pathogens from the body. Many of the neuroglial cells attach to blood vessels to constitute blood-brain barrier. The long process of a neurone (axon) may be myelinated; that is, surrounded by lipoproteins, involved in increasing the speed of conduction of impulses. Myelination in the peripheral nervous system, involved in saltatory conduction, is provided by Schwann cell or lemmocytes; while in the central nervous system, myelinated fibres are found in white gray matter where myelination is provided by oligodendrocytes. The gray matter constitutes mainly the cell body of the neurones, while the white matter is made up mainly of the axons.

Impulse propagation and conduction

The neurones, like other excitable cells, are bathed with extracellular and intracellular fluids. The extracellular fluid has higher concentration of cations, such as sodium, potassium, and calcium ions than intracellular fluid, while intracellular fluid has higher concentration of anions such as chloride, sulphate, and bicarbonate ions. When an excitable cell is stimulated, the membrane pores/gates are opened to allow an increase in flow (influx) of sodium ions into the interior of the cell in larger quantity. This renders the interior of the cell membrane to be positively charged, compared to the external part of the membrane.

The influx of sodium ions results in the increase in the membrane potential, and polarity of the cell membrane is reversed from the external positive charge to being negatively charged. The internal part of the cell membrane will be positively charged, and the external part is negatively charged. The negatively charged external membrane is due to the large quantity of anions (bicarbonate, sulphate, and chloride anions) that are left behind in the extracellular flud. Electrical phenomena have been well studied in large axons of invertebrates, which include the axons of giant squid (*Loligo*), crab (*Carcinus*) and cuttle fish (*Sepia*).

A nerve impulse is a propagated action potential. It transmits signals in an excitable cell from the receptor to the central nervous system and, thereafter, from this system to the effector. Many body activities are accomplished through nerve impulses, which are also involved in the control of physiological processes. Neurotransmitters are chemical molecules involved in the relay of nerve impulses (propagated action potential) from one neurone to another or from a neurone to a muscle cell through a morpho-functional junction called synapse. Transmission of impulses is converted from electrical to chemical transmission in the synapse. Neurotransmitter molecules are released in the from vesicles in synaptic knobs and they diffuse via presynaptic membrane to synaptic cleft, containing extracellular fluid, to interact with receptors at the postsynaptic membrane. If there are enough quanta of excitatory neurotransmitter molecules discharged, the postsynaptic receptor potential is excitatory. The neurotransmitter induces an increase in the potential of the postsynaptic membrane to the critical level of depolarisation, and all-or-none action potential is generated. If the excitatory postsynaptic potential does not increase to reach the firing level (threshold potential), a local response is produced. Local potential or response is not strong enough to induce an all-or-none action potential. If a local response is repeatedly generated, it induces the release of adequate quanta of neurotransmitter molecules to drive membrane potential to the firing level. Consequently, an action

potential is generated. Calcium ion enhances synaptic transmission. Synaptic transmission of impulses is a weak spot in mechanism of propagation of nerve impulse in excitable cells. This is because the neurotransmitter molecule may be blocked at the receptor sites. Conversely, it may be stimulated to induce the generation of enough quanta of neurotransmitter molecules. Many pharmacological and toxicological manipulations of neuronal activities occur at the synaptic level. A neurotransmitter molecule, after interacting with postsynaptic receptors, is usually broken down by an enzyme and the breakdown products diffuse back into the synaptic vesicles where the neurotransmitter is re-synthesized. Mostly, neurotransmitters are broken down by enzymes and their synthesis or re-synthesis also occurs via enzymes. For example, acetylcholine is broken down by acetylcholinesterase and synthesized by a transferase enzyme (choline transferase). Substances that mimic acetylcholine action are called cholinergic agents and those that block acetylcholine action are called cholinolytic or anticholinergic agents.

Classification of neurotransmitters

Neurotransmitters are classified as: Cholinergic (Acetylcholine); Adrenergic neurotransmitters, which are adrenaline (epinephrine) and noradrenaline (norepinephrine); Catecholamines: they are adrenaline, noradrenaline, and dopamine.; Monoamines are noradrenaline, dopamine, and serotonin; Amino acids, which are monocarboxylic and dicarboxylic amino acids. Acetylcholine is a potent excitatory and inhibitory neurotransmitter. It is predominantly inhibitory in the spinal neurones, but excitatory in brain and parasympathetic nervous system. Acetylcholine is a neurotransmitter in almost all excitable cells, and it constitutes a group on its own. The receptor site responding to acetylcholine neurotransmitter at postsynaptic membrane is cholinergic receptor. Based on this fact, the receptor site for a particular neurotransmitter may be glycinergic, gabaergic, glutamatergic. The interaction of neurotransmitter molecules with the receptors results in

the influx of sodium (Na^+) ion into the intracellular fluid from the synaptic cleft. This evokes an all-or-none action potential, converting nerve impulse propagation from chemical to electrical propagation. Neurotransmitters are recently found to possess other activities. For example, L-serine is a putative neurotransmitter (unconfirmed), now found to possess antioxidant and antistress activities. It is also a growth promoter in broiler chickens (Ogbuagu *et al.,* 2023). This is apart from its inhibitory effect on the nervous system. The monocarboxylic amino acid neurotransmitters include glycine, acetylcysteine, and serine. Putative neurotransmitters include L-lysine, L-alanine, taurine, and L-arginine. They are predominantly inhibitory. Adrenaline and noradrenaline are neurotransmitters involved predominantly in stimulating vascularsmooth muscle, particularly causing vasoconstriction. In the intestine and stomach, they increase smooth muscle contraction; but in the brain and coronary vessels, they relax smooth muscle, inducing vasodilation. These two neurotransmitters together with dopamine and serotonin are broken down by monoamine oxidase or catechol-O-methyltransferase. The neurotransmitters are often taken back into the synaptic vesicles without being broken down, a process called synaptic re-uptake of neurotransmitters. Monoamines are also involved in adaptational responses in animals. The dicarboxylic amino acid neurotransmitters are L-glutamate, L-aspartate; and gamma-aminobutyric acid, which is a potent inhibitory neurotransmitter. L-glutamate is a potent excitatory neurotransmitter, often inducing excitatory neurotoxicity. L-glutamate is available in Nigerian markets; used as spices (food additive) and is a strong stimulant of appetite. *Neuromodulators:* They are peptides that regulate pain, emotions, mood, and adaptation. Their receptors are concentrated in the limbic system, involved in emotion responses. The neuromodulators constitute endorphins and enkephalins, which are peptides that interact with opioid receptors in the brain. The endorphins are alpha-, beta- and gamma-endorphins. Enkephalins are mainly methionine-enkephalin and glycine-enkephalin. Neurotransmitters and

neuromodulators are collectively called neuroregulators. Many more neurotransmitters and neuromodulators are being discovered. For example, melatonin is currently considered a neuromodulator in nervous system, recently demonstrated to possess antioxidant and antistress activities in donkeys and in broiler chickens (Sinkalu *et al.*, 2020; Ake *et al.,* 2023).

Reflex mechanisms of the nervous system and types

Reflex is a response of the body to a stimulus accomplished through a specialised neuronal pathway, called a reflex arc. A reflex arc comprises, in the following order: receptor, afferent neurone, centre in the brain and/or spinal cord, efferent neurone and effector (organ of response). Many activities in the body occur through reflex mechanism, which include swallowing, vomiting, defaecation, salivation, and walking. Reflexes are classified based on their location or function. Examples are reflexes of the eye, which include corneal reflex, pupillary reflex, and blink reflex. Reflexes involving the spinal cord are spinal reflexes. Those located in the tendons are called tendon reflexes, such as patellar or knee-jerk reflex and achilles tendon reflex. Reflexes located deep within the body are called deep (profundal) reflexes, while those located on the body body surface are superficial reflexes. Deep reflexes are reflexes of tendons, ligaments, and joints, also called proprioceptive reflexes.

Reflexes are also classified based on their clinical importance. The clinical reflexes are reflexes of mucous membrane and skin. They are of clinical importance in diagnosis of diseases in animals. The corneal and conjunctival reflexes are reflexes of the mucous membrane. The cough and sneezing reflexes are the reflexes of the mucous membrane, and they are protective expiratory reflexes. The skin reflexes include reflexes of the withers, reflexes of the abdomen, and hoofs. According to Pavlov, reflexes may be conditioned or unconditioned. The unconditioned reflexes are inborn, involving specific reflex arc and permanently having specific neuronal centres. Examples are defaecation, swallowing and vomiting. Conditioned reflexes are reflexes that are acquired during the lifetime of the animal. They may be lost

after been acquired, if not consolidated through a process called coupling. They do not have a specific neural arc or neural centre. Conditioned reflexes constitute neurophysiological basis of animal behaviour and the function of higher cortical centre (brain), whereas the unconditioned reflexes constitute the function of the brainstem and spinal cord (lower nervous activity). Conditioned reflexes are involved in determining the types of nervous activities, and they are important in determination of animal behaviour and adaptation the environment. Animals that develop conditioned reflex quickly, adequately, and effectively adapt to the environment and they are very resistant to diseases, and vice-versa. Reflex mechanisms underlie the principle of physiotherapy, acupuncture, and reflex therapy, which are widely applied in control of livestock diseases.

Cerebrospinal fluid

This is an extracellular fluid secreted by choroid plexuses in ventricles and spinal cord. It contains nutrients that are supplied to brain and spinal cord cells. It participates in buffering capacity. It circulates in the brain cavities, and in the central canal of the spinal cord. The cerebropsinal fluid exerts cushioning effect against brain and spinal cord injury.

Motor functions of the spinal cord

The spinal cord and brainstem are powerful relay pathways for the nervous system. It conveys impulses from the peripheral part to central nervous system through the white matter, which comprises non-myelinated fibres. The fibres that convey impulses to the brain constitute the ascending pathways. Those that relay impulses from the brain to the peripheral receptors or the effectors are the descending fibres.

Ascending and descending fibre tracts of the spinal cord

The spinal cord, located in vertebral column, comprises support cells and long, thin, tubular bundle of nervous tissue, extending from the brain (Figure 1). It receives and transmits signals from peripheral

receptors, and the brain. The three major functions of spinal cord are as follows: (i). Conduction of motor impulses down the spinal cord; (ii). Conduction of sensory impulses in the ascending direction; and (iii). It contains centres that coordinate some reflexes.

Impulses are transmitted via axon bundles in the body in two pathways: *ascending and descending.* The descending pathways or tracts control voluntary movement, relay signals via the corticospinal tracts, starting from cerebral cortex to spinal motor neurones, and finally to the effectors (or organs of response). Information transmitted through ascending tracts or pathways, along the spinal sensory neurones to the brain constitutes the sensory signals that give information about the body position, temperature, pain, touch, and other sensory signals.

Spinal cord segments*:* The spinal cord is composed of segments. Each segment has paired right and left spinal nerves (mixed; sensory and motor). Nerve rootlets which are six to eight in number, emanate from left and right ventrolateral sulci and combine to constitute nerve roots. The dorsal and ventral roots that relay sensory and motor inputs, respectively merge to produce mixed spinal nerves (motor and sensory). The rootlets are components of peripheral nervous system. The descending and ascending fibres are involved in the motor function of central nervous system. When their activities are blocked, as may occur during anaesthesia, the motor functions are impaired and the sensory inputs are arrested, thus all sensory sensations are arrested, and pain perception is lost. The spinal cord is predominantly involved in conduction of excitation; that is, the propagation of nerve impulses. The spinal cord also contains centres that regulate activities of muscles of the limbs, neck, trunk, and pelvis. The spinal cord also contains neural centres that control tendon reflexes.

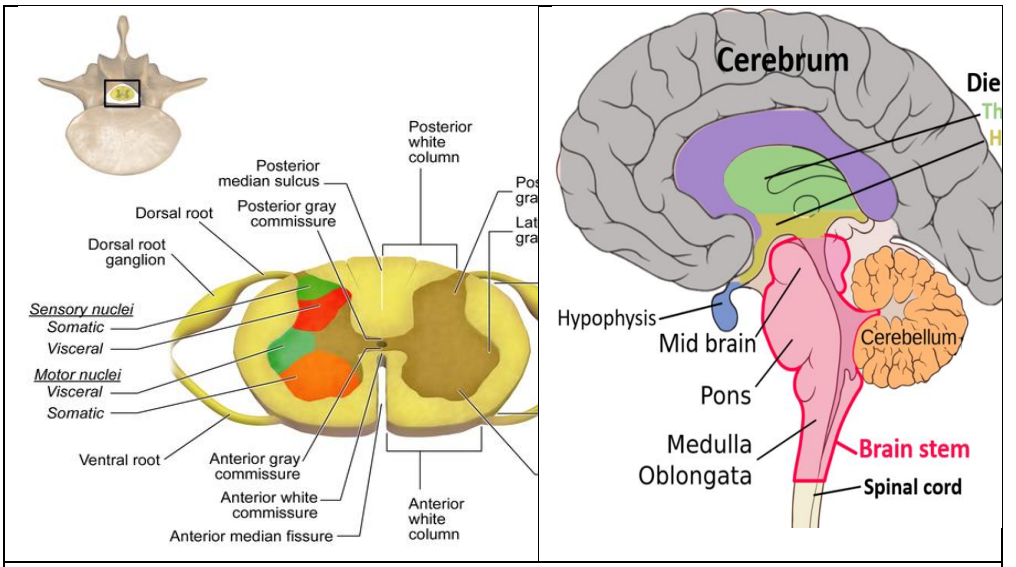

Figure 1: Cross section of the spinal cord and the brain

Brain, hypothalamus, and limbic system

The brain integrates most sensory signals and coordinates all body functions (Figure 1). It three major structures: the forebrain (telencephalon), midbrain (mesencephalon) and hindbrain (metencephalon). The cerebrum is the largest brain structure. The forebrain includes cranial nerves involved in contraction of muscles that regulate eye movement, and control of shape of the lens and diameter of the pupils. The midbrain contains reticular formation, which includes the tegmentum, a brainstem region that controls motor functions. The midbrain contains the *crus cerebri,* comprising nerve fibres that link the hemispheres of the cerebrum to the cerebellum. It also includes a dark nucleus called the *substantia nigra* that produces melanin. The midbrain and hindbrain form brainstem. This brain region participates in motor function, and auditory and visual responses. The *medulla oblongata*, pons and cerebellum, pons constitute the hindbrain. The pons and cerebellum control equilibrium, balance and locomotion, and relay of sensory signals (Figure 1). The *medulla oblongata* regulates involuntary

activities of the autonomic nervous system, including heart rate, digestion, and respiration.

Hypothalamus and limbic systems

The hypothalamus is the portion of the diencephalon involved in homeostasis, the relative maintenance of the body's internal environment. It links the endocrine and nervous and endocrine systems through the pituitary gland. The hypothalamus maintains some metabolic processes and control autonomic activities. It synthesizes neurohormones, called hypothalamic-releasing hormones, which stimulate or inhibit secretion of hormones of the pituitary gland. The hypothalamus regulates: (i). Autonomic nervous system; (ii). Hunger, appetite, and satiety; (iii). Important aspects of parenting and attachment behaviours; (iv). Body temperature. It is often regarded as the body's thermostat; (v). Fluid and electrolyte balance, including thirst; (vi). Production of hormones and substances that induce the release of hormones from the pituitary gland; (vii). Sleep and circadian rhythm; and (viii). Emotions and their effects on the body.

Hormones of the hypothalamus

The hypothalamus plays a significant role in the control of pituitary functions. After receiving signals from other parts of the nervous system, it secretes neurohormones that modulate the secretion of hormones by the pituitary gland. The hypothalamus secretes the following primary hormones: (i). Antidiuretic hormone and oxytocin; (ii). Corticotropin-releasing hormone; (iii). Gonadotropin-releasing hormone; (iv). Growth hormone-releasing (inhibiting) hormone or somatostatin; (v). Prolactin-releasing (inhibiting) hormone; (vi). thyrotropin-releasing hormone.

The limbic system includes many that connected and structures in cerebral cortex in the forebrain, telencephalon, and mid brain, diencephalon. They jointly control the functions of the autonomic nervous and endocrine systems, especially in responding to emotional situations. They involved in setting the arousal level, and motivation

and reinforcing behaviours. Most parts of these structures play crucial in differentiating memory types. The regions are linked directly connected to olfactory system. This is because this system plays a very important role in the survival of many animal species. Cortical regions involved in control of limbic system are the hippocampus and neocortex areas.

Sleep and wakefulness

Sleep is a potent inhibition relayed from the cerebral cortex to all other brain parts (active sleep) or due to absence of relay of sensory signals from peripheral receptors to the cerebral cortex (passive sleep). Mammals display robust daily and circadian rhythms of many physiological parameters, including behavioural parameters, known as biological rhythms. The circadian rhythm is approximately a 24-h cycle under the control of a master clock in hypothalamic suprachiasmatic nucleus, the mammalian biological clock. One of the most evident outputs of the circadian rhythm is the sleep-wake cycle, which is important for the health and homeostasis of an animal. Sleep is a form of adaptive and protective inactivity that reduces metabolism when conditions of living for the animal are not favourable. In animals, such conditions include a decline or absence of sensory responses and movement. Sleep allows suppression of activities when the animal is high predator risk and permits activities. It, however, ensures optimal activities at maximal times of availability of prey and minimal predator risk. It also enhances efficiency by reducing brain metabolic activities. Melatonin regulates sleep-wake cycle. It is secreted in the night, dark, hours. It regulates biological rhythms. Melatonin has been shown to exert antioxidant and antistress effects during the daytime; beneficial in alleviating road transport stress (Minka *et al*., 2013), and work and heat stresses in local livestock in Nigeria (Ake *et al*., 2023).

Autonomic nervous system

The autonomic (automatic, involuntary, vegetative) nervous system is a motor system that controls involuntary activities of cardiac and smooth muscles, and glands. The system is divided into three

subdivisions: (i). Sympathetic nervous system – participates in body's response to stress; fright, fight, and flight (3fs) reaction; (ii). Parasympathetic nervous system – returns body to resting state and conserves resources. Both systems exert opposite actions, though, not in all cases; and (iii). Enteric nervous system – controls smooth muscles of the gut.

Each autonomic nerve pathway relay signals to effectors through central nervous system to the effector organ consists of two-neurone channels. The cell body of the first neurone (preganglionic neurone) is in the central nervous system. In the ganglion, the axon forms synapse with cell body of second neurone, while axon of second neurone (postganglionic neurone) innervates the effector organ.

Sympathetic nervous system

It is also known as the *thoracolumbar division*. In this system, the axons emerge from the thoracic vertebrae (18 in horses and 13 in dogs) or first 4 – 6 lumbar vertebrae in horses, dogs, and cattle. The short preganglionic fibres (usually myelinated) leave the spinal cord and through the ventral roots to enter the paravertebral sympathetic trunk (ganglion of the sympathetic division). Fibres from vertebral ganglia innervate blood vessels, the eyes, salivary glands, heart, bronchi, sweat glands and hair follicles. Fibres that emerge from the prevertebral ganglia (coeliac, cranial, and caudal mesenteric) relay impulses to the intestine, stomach, bladder, rectal and urinary sphincters as well as genital organs. The longer postganglionic neurones then emerge from the sympathetic trunks to innervate the effector organs. Adrenal medulla, a modified postganglionic fibre of sympathetic nervous system, is embryologically and functionally connected to a sympathetic ganglion.

The stimulation of sympathetic nervous system alerts the body for immediate actions; elevates blood pressure by generalised vasoconstriction. There is bronchodilation to increase aeration of the lungs. This is followed by vasodilation of blood vessels supplying skeletal muscle. The sympathetic nervous system also increases heart

rate and force of myocardial contraction of heart muscle. It increases sweating and dilates the pupils for better visual acuity, especially for far vision; but digestive and urinary activities are inhibited. These activities are observed in fear, flight, or fight condition, also called 3fs syndrome.

Parasympathetic nervous system

It is the *craniosacral division* of autonomic nervous system. The pathway consists of a long preganglionic fibre and very short postganglionic fibres because the ganglia are located on the surface of, or within the effector organs. It is formed by oculomotor (III) cranial nerve, involved in pupillary constriction), facial (VII), glossopharyngeal (IX), and vagus (X) nerves, while sacral division emerges from sacral nerves (S_1 – S_3) to supply the remaining parts of gastrointestinal tract, including rumen. It also supplies the gall bladder, uterus, bladder, and the sex organs.

When in control, parasympathetic nervous system generally slows down activities that are enhanced by the sympathetic nervous system. It facilitates digestion and absorption by increasing motility and glandular secretion. The parasympathetic nervous system is involved in emptying of the bladder, increase in pupillary constriction and facilitation of accommodation for near vision. It also lowers heart rate and force of heart contraction, especially the atria. There are some exceptions to dual innervation of sympathetic nervous system and parasympathetic nervous system. For example, innervated blood vessels (arterioles and veins) receive only sympathetic innervation. Only blood vessels in the penis and clitoris have parasympathetic innervation. Furthermore, sweat glands have only sympathetic innervation; whereas salivary glands have both innervations, but their activities are not antagonistic. The sympathetic nervous system produces thick copious saliva, rich in mucin; while parasympathetic nervous system produces watery saliva, rich in enzyme and ions. Both preganglionic fibres of sympathetic and parasympathetic divisions of the autonomic nervous system release acetylcholine as their neurotransmitters. Postganglionic fibres of

parasympathetic nervous system release acetylcholine and are called cholinergic fibres with all preganglionic fibres. Sympathetic postganglionic neurones that innervate most sweat glands are also cholinergic. Most sympathetic postganglionic neurones release noradrenaline. Thus, they are referred to as adrenergic fibres/neurones.

Adrenal medulla: It secretes hormones directly into the circulation when stimulated by the sympathetic preganglionic fibre – from T_7-T_9. About 20% of hormones from adrenal medulla is noradrenaline, the remaining 80% is adrenaline. It reinforces sympathetic nervous system, responsible for mass action during 3fs syndrome. Recent advances have also shown the presence of postganglionic fibres that are cholinergic, and some neuropeptide Y and vasoactive intestinal peptide producing intrinsic innervation (Fedele and Brand, 2020).

Receptors in the autonomic innervation: Receptors are integral membrane proteins that bind with hormones, neurotransmittersand other chemicals. They induce the second messenger mechanism that produces the effector cellular response. There are two types of receptors that bind with acetylcholine (cholinergic receptors) from all preganglionic fibres and postganglionic parasympathetic neurones.

The two types of cholinergic receptors:
(i) Nicotinic receptors: Found in all ganglia of autonomic nervous system, and skeletal muscle motor endplate, and they respond to acetylcholine. The two subtypes of nicotinic cholinergic receptors are N_M and N_N receptors. The N_M receptors are in motor endplate of skeletal muscle. They are involved in contraction of skeletal muscle. The N_N receptors are found in all autonomic ganglia, spinal cord, some brain areas, and adrenal medulla.
(ii). Muscarinic receptors: Found on the effector cell membrane of smooth and cardiac muscles and glands. They respond to acetylcholine from parasympathetic postganglionic fibres. The subtypes of muscarinic

receptors are five, namely: M_1, M_2, M_3, M_4 and M_5, but M_1 (in gastric glands and central nervous system), M_2(heart) and M_3(visceral smooth muscle and exocrine glands) are important.

Adrenergic receptors: Found in visceral effectors, blood vessels and glands. The receptors respond to adrenaline and noradrenaline from the postganglionic sympathetic nerves. They are of two types: i. Alpha-receptors: The subdivisions are α_1, α_2; ii. Beta-receptors: Their subdivisions are: β_1, β_2, β_3. When activated, α_1- and β_1-receptors generally produce excitation, but stimulation of α_2- and β_2-receptors induces inhibition of the effectors. The β_1-receptor is found mainly in the heart. It causes excitatory actions, whereas β_3-receptors are located only on brown adipose cells, and their stimulation induces thermogenesis. Furthermore, noradrenaline is a more potent stimulus of α-receptors than β-receptors, while adrenaline is a potent stimulus of both α_2- and β_2-receptors. The activation of various receptor types elicits different responses to the same neurotransmitters, depending on the type of receptors on the effector. Based on these activities, receptors can, therefore, be manipulated by drugs, which activate (agonists) or block (antagonists) autonomic responses. Agonists and antagonists may be selective or non-selective. However, non-selective drugs may show some undesirable side-effects due to their effects on other receptors. For example, Propranolol, a non-selective beta-blocker, used to treat hypertension due to its effects on β_1-receptor, may also cause hypoglycaemia and mild bronchoconstriction, whereas Metoprolol, a selective β_1-blocker is prescribed if the above effects are undesirable like in asthma patient that is also hypertensive. Atropine blocks acetylcholine at the muscarinic receptors and does not affect nicotinic receptors. It could, therefore, be used to suppress salivation, bronchiolar secretions and stimulate paralytic ileus during surgery. Salbutamol selectively activates β_2-adrenergic receptors. At low doses, it is often used to stimulate bronchial dilation in asthma patients, without stimulating the heart, which has β_1-adrenergic receptor. The

hypothalamus is the integrating centre for all autonomic responses that accompany various emotional behavioural states, including increase in blood pressure, heart rate and respiratory activities during anger and fear. It acts via the hypophysis and adrenal medulla.
The enteric division of autonomic nervous system is made up of the myenteric or Auerbach's plexus found between the circular and longitudinal layers of smooth muscle of the gastrointestinal tract which regulates motility; and the submucosal or Meissner's plexus found within the submucosa, which stimulates the glands along the gastrointestinal tract to increase secretions in response to distention or presence of some products of digestion.

Special Senses

Senses are modalities through which internal and external environments are perceived. Perception on the other hand is the conscious interpretation of sensations through the cerebral cortex that helps us to rationalise or makes sense of information related to various sensory modalities from all parts of the body. Senses are basically divided into two: (i). General senses, comprising visceral and somesthetic senses. They include touch, pressure, temperature, and proprioception. (ii). Special senses, which are senses from specialised organs of reception located in the head. They are the sense of vision, taste, hearing, equilibrium, smell and taste.

***Vision*:** Vision is the act of seeing, detected by photoreceptors (rods and cones) in the retina. The organ of vision is the eye. Like a camera, the eyeball has a lens, an aperture (the pupil) that can increase or decrease in size to control the quantity of light rays; and retina (the film). It is enclosed by three layers: sclera, choroid and retina within which the photoreceptors are located (Figure 2). When photoreceptors in the retina are stimulated, impulses are transmitted by the optic nerve through the thalamus to the visual (occipital) cortex for interpretation. There are also contributions from the lateral geniculate nucleus (thalamus), which helps in the screening of unwanted sensory inputs,

superior colliculus and pretectum, for control of eye movement and pupillary reflex, respectively; and suprachiasmatic nucleus of the hypothalamus for onward control of diurnal and circardian rhythms and hormone changes.

Accommodation: This is defined as the process by which the lens changes shape to focus on close objects. The lens, in conjunction with the cornea, is responsible for focusing of incoming light rays. If light rays are coming into the eye from a distant object, the lens is flattened; but for a close object to be focused, the lens thickens as the ciliary muscles contract and relax the suspensory ligaments.

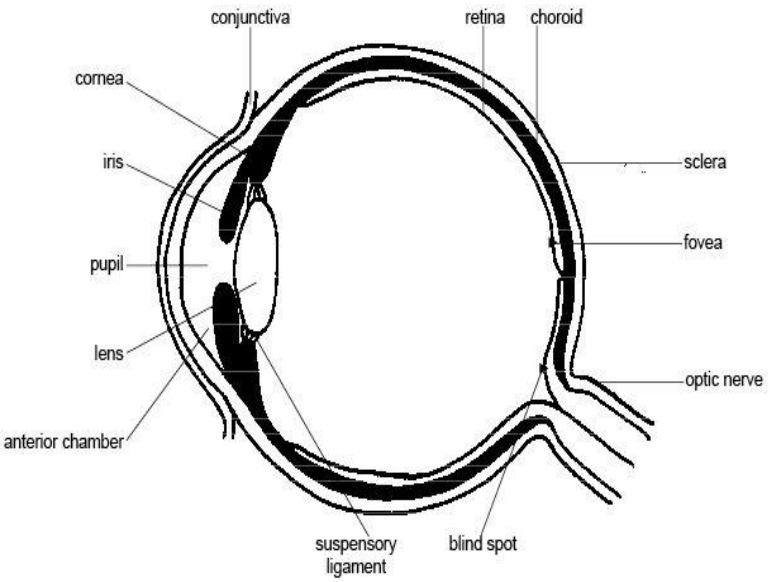

Figure 2: Structure of the eye
https://upload.wikimedia.org/wikipedia/commons/6/64/Anatomy_and_physiology_of_animals_Structure_of_the_eye.jpg

Hearing: This is the perception of sound waves. The sense organ is the ear. It consists of the external auditory meatus, tympanic membrane, ear ossicles (malleus, incus and stapes), the cochlea (which

houses the organ of Corti, the receptor for sound detection), vestibule and semicircular canals (Figure 3).

Mechanism of hearing: Sound waves are converted by the tympanic membrane and auditory ossicles into vibrations or movement in the footplate of the stapes. The movements create waves in the fluid in the cochlea, which stimulate the organ of Corti to generate action potentials through vibrations in the tectorial membrane and the associated movement of the cilia in the hair cells.

Static and dynamic equilibrium are also maintained by the movement of cilia on the hair cells located in the vestibule (macula) and semicircular canals (*crista ampularis*), respectively, according to the position or movement of the head.

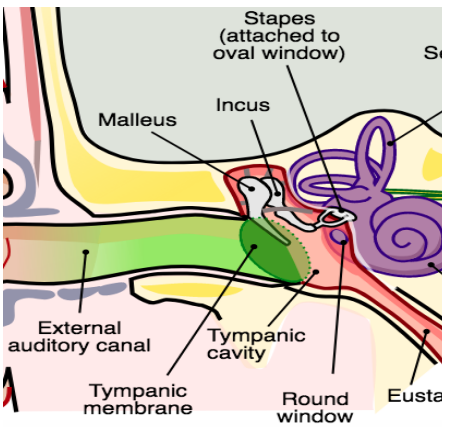

Figure 3: Structure of the middle and inner ear

Olfaction: This is the detection of odour or smell by olfactory cells in the mucous membrane of the nasal cavity. This sense is important in animals with projections to the limbic system, including septal nuclei and amygdala for pleasure motivation,

hippocampus for motivational memory and hypothalamus for autonomic and hormonal effects on sexual arousal, reproductive cycle.

Olfaction is also involved in pheromone secretion and recognition, salivation, predation, territoriality and other social behaviours. Some animals possess specialized organs for detection or dissemination of pheromones; for example, vomeronasal organ and tarsal glands.

Gustation: This is the detection of taste by receptors in the taste buds on the papillae, especially foliate, fungiform and circumvallate papillae on the tongue of domestic animals. There are five taste modalities, they include: bitter, sweet, sour, salt, and umami tastes. Flavour results from the combination of the basic tastes and odours derived as the materials dissolved in saliva; perceived by the specific receptors, depending on the type of chemical composition.

Muscle Physiology

Overview: Muscle is an excitable tissue that can transmit impulse along its membranes. It responds to stimuli by activating a contractile mechanism. There three types of muscle: skeletal, smooth, and cardiac muscle. The skeletal muscles form the musculoskeletal system in association with bones. The simple muscle contraction curve can be demonstrated with sciatic nerve-gastrocnemius muscle preparation in a frog, the study of general electrical events and contractile activities of the muscle is called electromyography. The understanding of muscle physiology will help us to understand the mechanism of diseases such as muscular dystrophy, hypertonia, *etc*.
Introduction: Muscle, as an excitable tissue, can be stimulated electrically, chemically, or mechanically to generate an action potential, which is transmitted along the entire cell membrane. Muscles are made up of contractile proteins, actin, and myosin - the primary structural components that bring about contraction. The skeletal muscles form about half of the body mass and are both striated and voluntarily controlled. These muscles are innervated by somatic nerves. Fibres of the skeletal muscles are generally arranged in parallel as they are attached to bones with tendons at both ends. The cardiac muscle,

though striated, is involuntarily controlled through the autonomic nerves and found only in the heart. The smooth muscles on the other hand are found in the viscera - the GIT, ductus deferens, uterus, ciliary muscle, and arterial walls etc. That is why it is also called visceral muscle. Unlike the skeletal and cardiac muscles, they lack cross striations, hence the name smooth muscle (Table 1).

Table 1: Special Features of Muscles

Characteristics	**Skeletal muscle**	**Cardiac muscle**	**Smooth muscle**
Location	In association with bones	In the heart	In the visceral organs
Shape	Cylindrical and unbranched	Branched spindle-shaped,	Unbranched
Number of nucleus	More than one	One	One
Cross-striations	Present	Present	Absent
Myofibrils, Sarcomere, troponin	Present	Present	Absent
Depolarisation	Upon stimulation	Spontaneous	Spontaneous
For trigger of contraction, calcium binds with	Troponin	Troponin	Calmodulin
Source of calcium	Sarcoplasmic reticulum	Sarcoplasmic reticulum	Extracellular
Speed of contraction	Fast	Intermediate	Slow
Nerve supply	Somatic nerves	Autonomic nerves	Autonomic nerves

Structure of skeletal muscle: The skeletal muscle is made up of large, multinucleated and elongated cells known as myofibres. Each muscle fibre is a multinucleated, long, cylindrical cell bounded by elastic cell membrane also called sarcolemma. The cells are grouped into bundles (*fasciculi*). Each muscle fibre is composed of several thread-like structures known as myofibrils. A typical muscle fibre is 2 – 3 centimetres long and 0.05 millimetres in diameter, within which are the myofibrils. The myofibrils contain thick and thin myofilaments, which are made up of the proteins: actin and myosin. Numerous capillaries supply the muscle with the oxygen and glucose needed to fuel contraction. The myofibrils form the cross striation in striated muscle because of the alternating light and dark bands. The dark band is known as A-band, while the light band is called I-band. The functional unit of the myofibril is known as the sarcomere. Each sarcomere is composed of one A-band, flanked on either side by one-half of an I-band. The dark line bisecting each I-band is called Z-line. Within each sarcomere are two myofilaments: actin and myosin. Closely associated with the myofibrils are two membrane structures: sarcoplasmic reticulum and T-tubule (invagination of the sarcolemma). The sarcoplasmic reticulum contains high concentration of calcium ions (Figure 4).

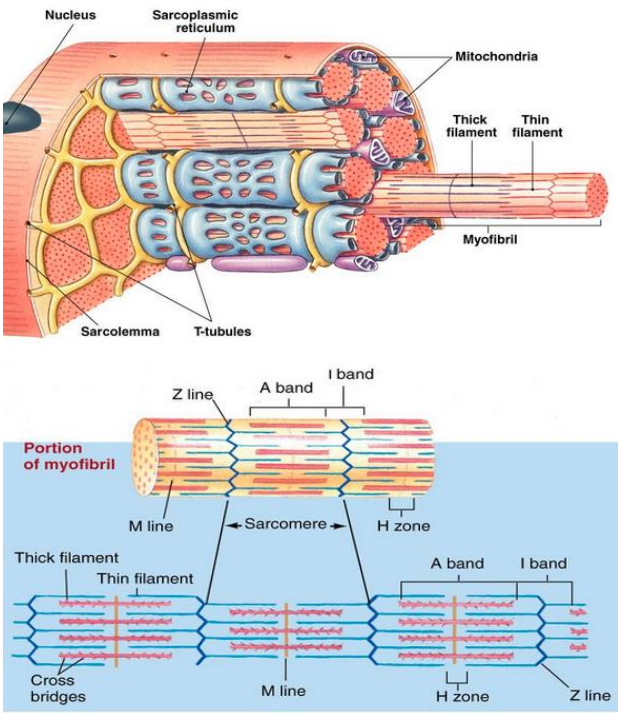

Figure 4: The ultrastructure of a muscle cell
https://www.austincc.edu/apreview/PhysText/Muscle.html

Muscle contraction: Acetylcholine is the neurotransmitter released by motor nerve at the motor endplate, which generate an end-plate potential, leading to the depolarisation of the sarcolemma. The electric impulse so generated in the plasma membrane flows into the T tubule stimulating the release of Ca^{2+}ions from the sarcoplasmic reticulum into the cytoplasm. Thereafter, Ca^{2+}ions combine with troponin and the movement of Ca^{2+}, troponin-tropomyosin complex, reveals the receptor site therefore allowing cross bridges to form between actin and myosin. Myosin heads then attach to the actin in the presence of ATP. The head of myosin cross-bridges bend backwards, pulling actin towards the centre of the sarcomere in a process called power stroke, at the expense of ATP. The ATP is thereafter hydrolysed and the cross-bridge relaxes and returns to the previous shape. When a new ATP occupies the vacant site on the myosin head, this triggers detachment of myosin

from actin. The free myosin swings back to its original position and is attached to another actin and the cycle repeat itself.

Contractility is the response of the muscle to a stimulus while contraction is defined as change in length or tension of muscle fibres when stimulated. There are two types of muscle contractions, isotonic and isometric contractions. Isotonic contraction occurs when the tension of the muscle remains the same whereas the length of the muscle fibre decreases (iso = same: tonic = tension). This is seen in simple flexion of arm, with a shortening of muscle fibres, while the tension remains unchanged. Isometric contraction on the other hand, is seen when the length of muscle fibres remains unchanged whereas the tension is increased. This is seen when pulling heavy objects when muscles remain rigid and inelastic with increased tension, but the length remains the same.

Fatigue: This can be defined as the failure of muscle contractility following repeated stimulation. When stimuli are applied repeatedly, after some time, the muscle does not show any response to the stimulus. Causes of fatigue include (i). Exhaustion of acetylcholine in the motor endplate (ii). Accumulation of metabolites such as lactic acid and phosphoric acid, (iii). Lack of nutrients and oxygen required for muscle contraction.

Tetanus: This is defined as sustained muscle contraction because of repeated high frequency stimuli. Skeletal muscles are known to have long relative refractory period during which the muscle can still respond to high frequency stimuli and further contract without complete relaxation. Thus, the muscle remains in a state of tetany or sustained contraction. Tetany is only removed upon the removal of the stimulus, or when the muscle gets fatigued.

For muscle contraction to take place, it requires energy. This energy is derived from ATP hydrolysis. Only about 25% of the energy produced is used for mechanical activity. The remaining 75% is dissipated as heat. But not all the heat is liberated at once. It is released in different stages; for example, resting heat is produced when a muscle is at rest due to metabolic process occurring within the muscle. The initial heat is produced during the initiation of muscle contraction, contraction of

muscle and muscle relaxation. The heat is produced as a result of the release of calcium ions from longitudinal tubules, and from various structural changes takin place in the muscle fibre; like movements of cross-bridges and myosin heads, and breakdown of glycogen and ATP molecule, respectively. The heat produced in the muscle after the end of activities is known as recovery heat because of re-synthesis of chemical substances broken down during contraction.
Electromyography is the study of electrical activities of the muscle, while electromyogram is the graphical representation of these electrical activities. Electromyogram is useful in the diagnosis of neuromuscular diseases, such as motor neurone lesions, peripheral nerve injuries and myopathies.

Bone Physiology

Bone is a connective tissue that provides physical and spatial support, allows movement to occur, and protects vital organs. It is also important in the control of mineral and acid - base balance and provision of the environment for haematopoiesis (production of blood cells) in the bone marrow. Bone is a connective tissue because it consists of cells (osteocytes) which makes up about 10 % of the total bone volume, suspended in extracellular matrix. There are four types of cells in the bone, they are: (i). Osteoblasts (bone-forming cells) that synthesise the bone matrix (osteoid); (ii). Osteoprogenitor (stem) cells that are still capable of forming the osteoblasts; (iii). Osteocytes whose primary function is mechanosensation by detecting mechanical loading through physical deformation of bone matrix and flow of canalicular fluid; and (iV). Osteoclasts - bone-resorbing cells. They are large, multinucleated cells derived from precursors of monocytes and tissue macrophages.
Bone extracellular matrix: This makes up 90% of overall bone volume. It consists of inorganic (mineral) and organic matrices. Inorganic bone matrix accounts for 99% of the body storage of calcium, 85% of the phosphorus, and 40-60% of the magnesium, and sodium. It is mainly in the form of hydroxyapatite to provide the bone its strength, stiffness, and resistance to compressive forces. Organic bone matrix: is secreted

by osteoblasts and is predominantly type I collagen. It also contains glycoproteins, growth factors, and proteoglycans. Growth factors (such as osteocalcin, osteonectin, and bone sialoprotein) play important roles in osteoid formation, mineralisation, and bone remodelling. The organic matrix gives bone its form and provides resistance to tensile forces.

Bone remodelling: This is the process of removal of old or damaged bone matrix by osteoclasts and replacement with new bone by osteoblasts. This process essentially requires all the four types of cells in the bone, with bone resorption well coordinated and synchronised with bone formation to prevent any net change in bone mass or quality after each remodelling.

*Principles of growth and development***:** Skeletal growth continues until well after puberty, when the rate of growth in length of long bones starts to decrease, while the diameter of bones continues to increase until maturity. Castration prolongs skeletal growth, especially long bones, and retards increase in bone diameters. The skeletal size and, probably, bone physiology of animals vary due to the effects of natural selection and adaptation of the various breeds or types to different ecological regions.

Summary

The nervous system serves as the fast-acting control centre for body activities. It is divided into the central and peripheral nervous systems. The central nervous system is made up of the brain and the spinal cord, while the peripheral nervous system is subdivided into somatic and autonomic nervous system. It consists of neurones, which are the basic functional unit and neuroglial cells that perform supportive roles and formation of myelin sheath for saltatory conduction. Electrical impulses are transmitted from neurone to neurone through chemical messengers called neurotransmitters at the synaptic junctions, and the activities of these neurotransmitters are essential in the integrative control of body activities by the brain. The neurones form nerves that conduct impulses to and from the brain, while the interneurones work at the integrating centres. The autonomic nervous system provides innervation for organs that are autonomous, devoid of voluntary control and is divided into:

sympathetic nervous system, which prepares the body for actions or active during fear, anxiety, fight and flight syndrome and exercise; and parasympathetic nervous system, which dominates during the quiescent period. Muscle cells are excitable cells consisting of contractile proteins, actin, and myosin, which contract and relax to facilitate movement of the skeletal, smooth, and cardiac muscles. Skeletal muscles are supplied by somatic nerves and anchored to the bones by the tendons, while the cardiac and smooth muscles are innervated by the autonomic nervous system, devoid of voluntary control.

Exercises

1. What are neuroglial cells? Discuss their roles in the nervous system.
2. Discuss the roles of hypothalamus in regulating vegetative functions.
3. What are the effects exerted by sympathetic nervous system during fright, fight, and flight syndrome?
4. Write short notes on excitation-contraction coupling in the skeletal muscle.
5. Describe the mechanisms of hearing and equilibrium.

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Chapter 7

VBC 201: Biochemistry I

(Chemistry and Biochemistry of Carbohydrates and Proteins Abnormalities of Carbohydrate and Protein Metabolism)

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Overview

Veterinary Biochemistry 201 focuses on pathways of metabolism of glucose, fructose, control of carbohydrate metabolism, the electron transport chain (ETC) and oxidative phosphorylation. Chemistry and structure of amino acids, peptides, peptic bonds, metabolism of amino acids, amino sugars, essential and non-essential amino acids, together with classification, structure and functions of proteins are discussed. Urea cycle and its biochemical importance, glucose-6-phosphate dehydrogenase (G6PD) deficiency, inborn errors of metabolism of some amino acids, structure, properties, biochemical functions of haemoglobin, porphyrins, porphynurias, functions of bile pigments, biochemistry of jaundice in addition to haemoglobinopathies are among the components of VBC 201.

Objectives

The objectives of this course are to:

1. discuss the chemistry of carbohydrates and various pathways they are metabolized;

2. describe oxidative phosphorylation with respect to electron transport chain;
3. explain the chemiosmotic theory, couplers and uncouplers;
4. differentiate between essential and non-essential amino acids;
5. classify proteins and enumerate their functions;
6. describe the biosynthesis of urea and list the importance of urea cycle;
7. identify different hemoglobinopathies, discuss the causes and their sequelae;
8. understand the relationship between Glucose 6 phosphate dehydrogenase deficiency and hemolytic anaemia;
9. relate some inborn errors of protein metabolism with their etiologies; and
10. describe hemoglobin metabolism and jaundice; and various porphyrias of animals.

Chemistry of carbohydrates

Carbohydrates are defined as polyhydroxy aldehydes or ketones or compounds that can be hydrolysed to yield them giving rise to aldoses and ketoses. These molecules are formed from proceeds of the carbon cycle. A polyhydroxy aldehyde is called an aldose (example, glucose, galactose, mannose) while a polyhydroxy ketone is called a ketose (example, fructose). Carbohydrates are important as diets/energy and as components of cell membranes/cell wall, connective tissues (chitin, hyaluronic acids) and hereditary materials (RNA and DNA).

Classification and nomenclature of carbohydrates (CHO)

Monosaccharides are CHO with an unbranched chain of 3 to 8 carbon atoms (example, glyceraldehyde, dihydroxyacetone, glucose, fructose etc). The most abundant naturally occurring monosaccharide in animals is glucose. Monosaccharides are also classified based on the number of carbons (example, triose, tetrose, pentose, hexose etc.) and type of functional group (example, aldopentose and ketohexose**).** Disaccharides are sugars made of two monosaccharides linked together by a bond called a glycosidic bond (example, maltose, lactose, and

sucrose etc). Oligosaccharides are sugars made up of 3-10 monosaccharide units joined together (glycosidic bonds) example, stachyose in whole grain). Polysaccharides are long chain polymers of monosaccharide units consisting of 10 to 100s or 1000s of simple sugar units. They may be linear**-** (example, cellulose, amylose form of starch) or branched**-** (example, amylopectin, glycogen), homo**-** (same sugar units e.g., glycogen, starch, cellulose) or hetero**-** (2 or more different sugar units' example, pectin, hyaluronic acid). Polysaccharides are sometimes classified as hexosans or pentosans depending on the constituent monosaccharide.

Structural orientation of monosaccharides

Monosaccharides are represented in 2- and 3-dimensional ways. The open chain structure (or Fischer projection**)** and cyclic structures (or Haworth projection**)** because of hemiacetal or hemiketal reaction between the aldehyde group and a hydroxyl group of a monosaccharide giving rise to Pyranose and Furanose rings.

Stereoisomerism

Stereoisomers are molecules with the same chemical formula, the same molecular structure, but different spatial arrangement. There are two types of stereoisomerism: geometric (*cis, trans configurations*) and optical isomerism (*D and L notations* resulting in chiral or asymmetric centre enantiomers, diastereomers, epimers). Geometric isomerism is encountered in pheromones used by insects for tracking and changes in rhodopsin during night vision whereas deficiency results in night blindness. Naturally occurring carbohydrates are of the D-notation. Carbohydrates that can rotate the path of plane polarized light (in a polarimeter) in a clockwise direction are termed dextrorotatory **(+)** whilst those that rotate plane polarized light anticlockwise are called levorotatory **(-)**. Solutions of sugar with equal dextrorotatory and levorotatory are called racemic mixtures or racemate. Cyclic monosaccharides also display optical activity because of the presence of anomeric carbon atoms or anomers (α and β notation example, α-D-glucose, β-D-glucose). Anomers also undergo mutarotation.

Chemistry of different carbohydrates

Monosaccharides are carbon hydrates with unbranched chain of 3 to 8 carbon atoms. Glucose **(**$C_6H_{12}O_6$) is a pentahydroxy aldehyde, an aldohexose with 2^4 isomers which can undergo mutarotation. Abnormal glucose metabolisms result in hyperglycemia or diabetes mellitus. Galactose is also an aldohexose that differs from glucose only in the position of the OH group on C4. Galactose is found in the cellular membranes of the brain and nervous systems. Abnormal metabolism of galactose in animals results in clinical conditions called galactosemia. Fructose is a ketohexose found in fruit and honey. It undergoes mutarotation in solution. Mannose is found in immunoglobulins. Most of the monosaccharides mentioned undergo the following chemical reactions: mutarotation, oxido-reduction reactions (e.g., Benedict's test, glucitol or sorbitol, mannitol, xylitol, glucuronic and uronic acids), dehydration (Molisch test), formation of phosphate sugars (example, glucose-6-phosphate), glycoside formations (formation of disaccharides, oligosaccharides, and polysaccharides) and formation of amino sugars (antibodies, glycoproteins, and gangliosides).

Disaccharides are sugars made of two monosaccharides linked together by a bond called a glycosidic bond. Maltose is called malt sugar and consists of two glucose units joined by α-1,4-glucosidic bond. Cellobiose has two glucose units linked by β-1,4-glucosidic bond and is a reducing sugar and undergoes mutarotation. Isomaltose is made up of 2 glucose units with α-1,6-glucosidic bond. Lactose, also known as milk sugar, is a galactose-glucose compound joined by a β-glycosidic bond (β-1,4-glycosidic bond). It is implicated in lactose intolerance. Sucrose or cane sugar comprises of fructose and glucose linked by α-1,2-glycosidic bond. Sucrose is not a reducing sugar because the glycosidic bond ties up the anomeric carbon of both monosaccharides with no reaction to Benedict's reagents.

- Amylose is the unbranched form of starch comprising between 5,000-500,000n glucose residues linked by α (1 - 4) bond.
- Cellulose is a linear β (1 - 4) polymer of glucose (containing 300 - 25,000 residues).

- Glycogen is an edible, highly branched glucose polymer comprising linear segments of α-(1,4) glucose with branches at about every 8 - 10 glucose residue by virtue of α (1 - 6) linkages.
- Amylopectin is the branched form of starch. It resembles glycogen except that the branches are further apart (low degree of branching), about every 25 glucose residues on average.
- Dextran (a volume expander) is linear chain polysaccharide consisting of α-1,6-glycosidic linkages between glucose molecules, while branches are at α-1,3-linkages.
- Hyaluronic acid is a heteropolysaccharide consisting of alternating units of gluconic acid and N-acetylglucosamine linked by α-1,3-glycosidic bonds cushions and lubricates joints. It is used medically in the treatment of both rheumatoid and osteoarthritis.
- Chitin is a rigid structural polysaccharide skeleton of insects, crabs, lobsters, and shrimps (crustaceans). It is a homopolymer of *N*-acetylglucosamine units linked by β-1,4-bonds. It is highly resistant to hydrolysis.
- Heparin is an acidic anticoagulant polysaccharide consisting of repeating units of sulphated glucosamine and sulphated iduronic acid joined by β-1,4-glycosidic bonds.

Metabolism of glucose and other sugars

All the chemical reactions (both anabolic and catabolic) in living cells involving nutrients are defined as metabolism. Knowledge of metabolism is essential for the understanding of abnormalities underlying diseases (example, nutritional and enzyme deficiencies, abnormal secretion of hormones, actions of drugs on metabolism and toxins). Metabolic pathways are categorized into anabolic pathways (example, gluconeogenesis, glycogenesis etc.) while catabolic pathways include glycolysis, glycogenolysis etc. A common example of amphibolic pathway is the tricarboxylic acid cycle.

Metabolism is further categorized into three. The primary (example, GIT digestion), secondary (GIT nutrients are absorbed and degraded to release reducing equivalents like NADH, FADH) and tertiary metabolism

(involves cellular respiration via the electron transport chain that generates more ATPs). Degradation of glucose to pyruvate is called glycolysis. It is defined as the sequence of reactions that converts glucose to pyruvate with the generation of ATP and is basically classified into two phases (priming and energy yielding phase). Glucose is phosphorylated to glucose-6-phosphate, isomerized to fructose-6-phosphate and phosphorylated to fructose-1,6-bisphosphate. Fructose-1,6-bisphosphate is cleaved to dihydroxyacetone phosphate and glyceraldehyde-3-phosphate in the first phase. Dihydroxyacetone phosphate cannot go down the pathway, so it's converted to another glyceraldehyde-3-phosphate. Glyceraldehyde-3-phosphate is converted to 1,3-bisphosphoglycerate (with the release of NADH) and to 3-phosphoglycerate via a substrate level phosphorylation. The 3-phosphoglycerate is isomerized to 2-phosphoglycerate and then dehydrated to phosphoenolpyruvate. Phosphoenolpyruvate is irreversibly converted through a second substrate level phosphorylation to pyruvate. Thus, a net gain of 2ATP and 2NADH molecules is achieved (see Figure 1).

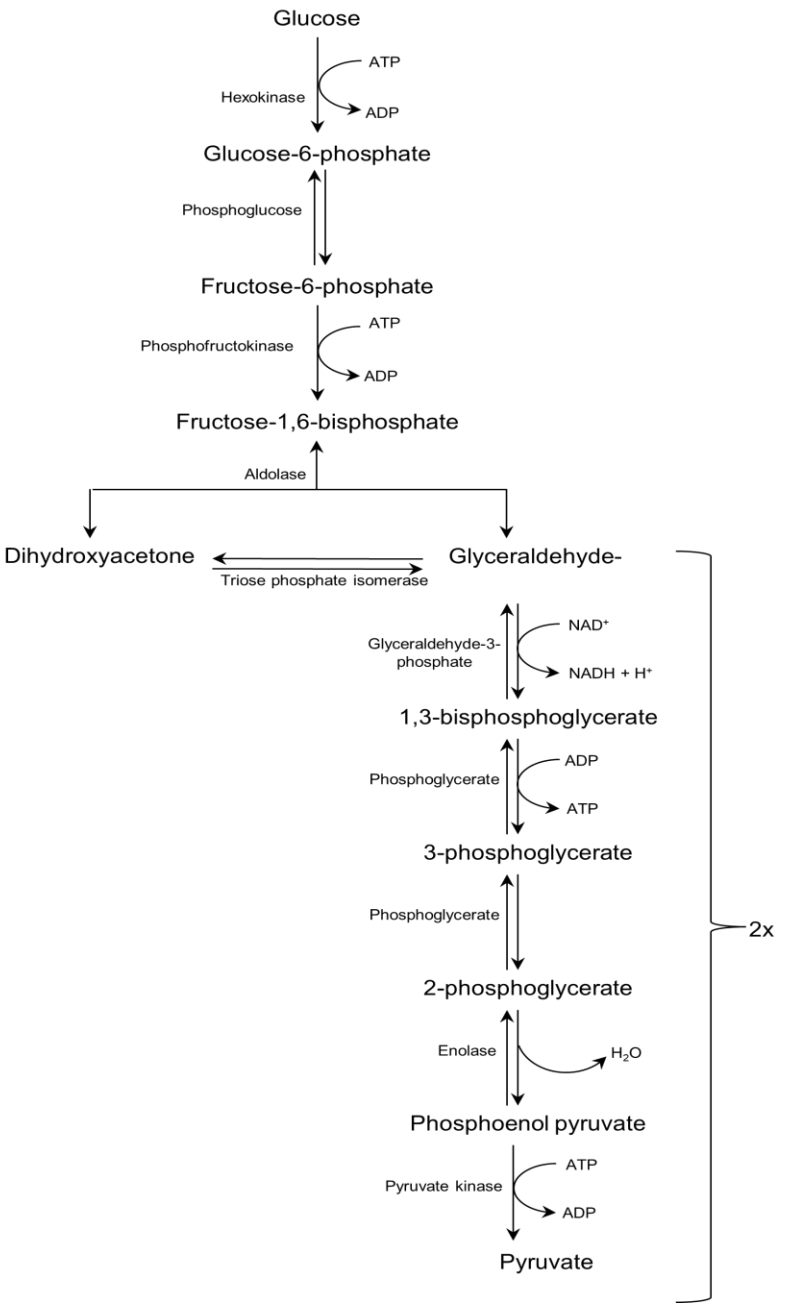

Figure 1: Glycolytic Pathway

Fructose enters the glycolytic pathway via glyceraldehyde and dihydroxyacetone phosphate where it is first phosphorylated to fructose-1-phosphate. Mannose is phosphorylated to mannose-6-phosphate and then isomerized to fructose-6-phosphate, an intermediate metabolite of glycolysis. Galactose is first phosphorylated to galactose-1-phosphate, then isomerized to glucose-1-phosphate and glucose-6-phosphate which enters glycolysis.
Pyruvate can undergo any of the four pathways i.e., oxidative decarboxylation to acetyl coenzyme A (acetyl CoA) and then tricarboxylic acid cycle (called aerobic glycolysis) or to lactate (known as anaerobic glycolysis) or back to glucose via a series of reactions similar but not the same with glycolysis (also refer to as gluconeogenesis) or to ethanol via acetaldehyde termed alcoholic fermentation.

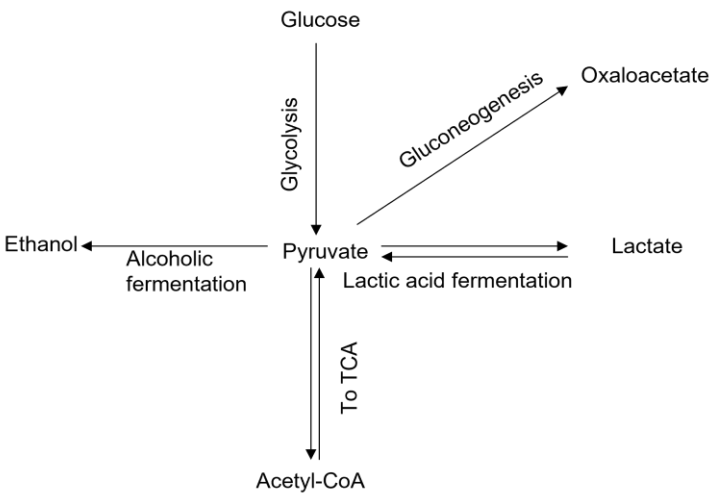

Figure 2: Fates of Pyruvate

Clinical Applications: Hereditary deficiency of phosphofructokinase in animals results in subjects getting fatigued easily due to poor ATP yield.

Lactic acid accumulation is implicated in muscle cramps in horses called Monday Morning Sickness.

Gluconeogenesis (defined as generation of glucose from other carbon skeleton) and glycolysis are opposing metabolic pathways and share several enzymes but with four new reactions that bypass the irreversible reactions of glycolysis catalysed by pyruvate carboxylase, phosphoenolpyruvate carboxykinase, fructose-1,6-bisphosphatase and glucose-6-phosphatase. Therefore, we have gluconeogenesis of lactate, glycerol, amino acids (utilizing glucogenic amino acids) and propionate (found in ruminant metabolism) (see Fig 3).

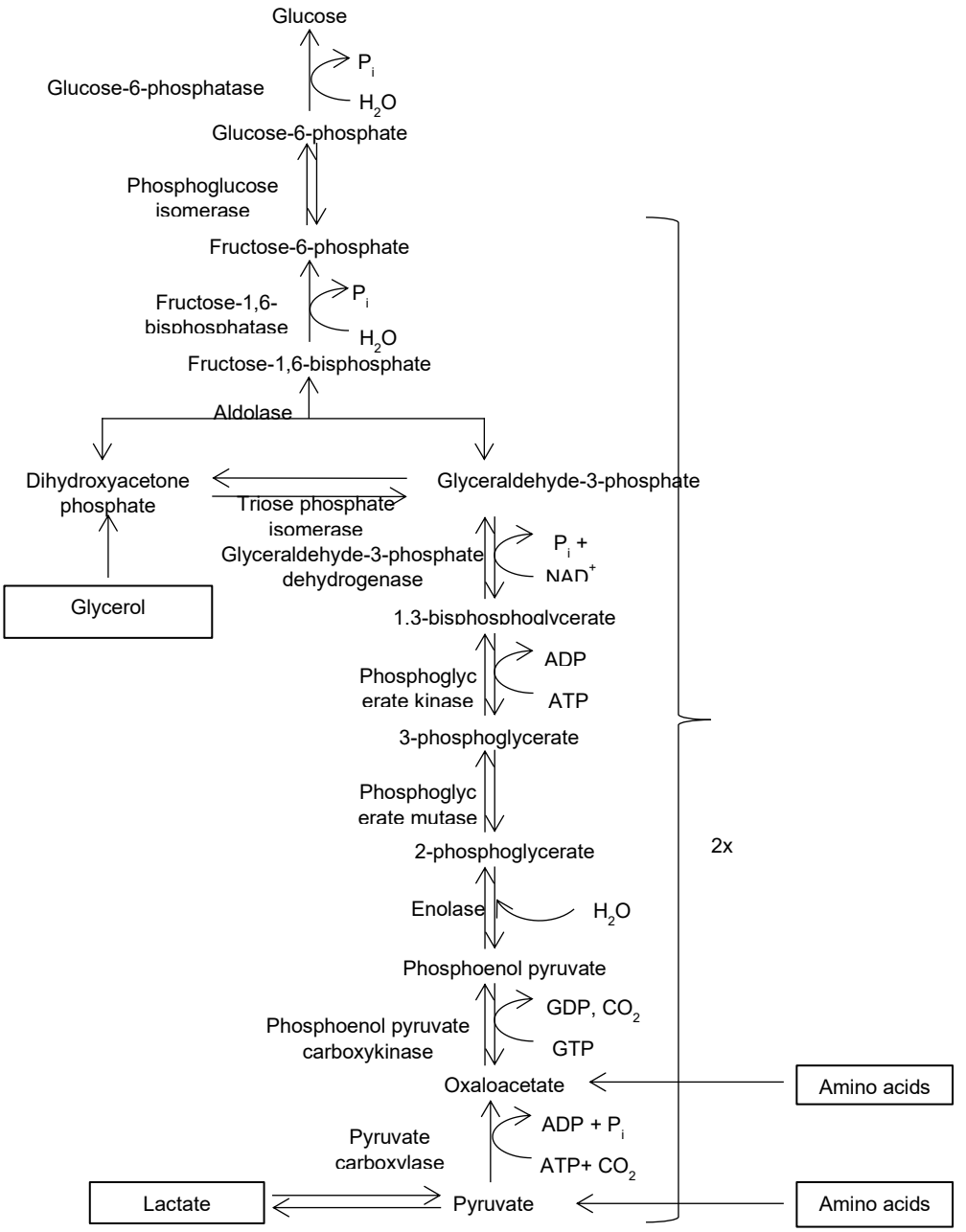

Fig. 3: Gluconeogenic Pathway

Metabolism of Glycogen

Glucose-6-phosphate in glycolysis can be channeled into the following pathways: glycogenesis and pentose phosphate pathway (phosphogluconate or hexose monophosphate shunt) according to the needs of the cell. During hyperglycaemia, formation of glycogen (Glycogenesis - a large polymer of glucose residue linked by α-1,4- and α-1,6-glycosidic bonds) starts with isomerization of glucose-6-phosphate to glucose-1-phosphate. Glucose-1-phosphate is converted to uridine diphosphate glucose (UDP-glucose) which donates one glucose unit at a time to an already existing glycogen molecule. Glycogen can then be broken down to glucose via glycogenolysis during transient starvations or hypoglycemia. Glucagon and epinephrine trigger a series of reactions that culminate in the phosphorolytic cleavage of the α-1,4- and α-1,6- glycosyl bonds of glycogen releasing glucose-1-phosphate which is isomerized to glucose-6-phosphate and later glucose.

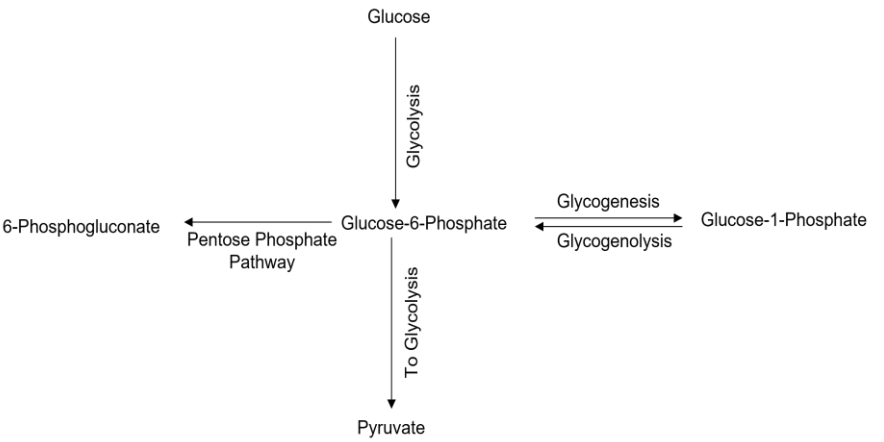

Figure 4. Fates of Glucose-6-Phosphate

Pentose phosphate pathway (phosphogluconate or hexose monophosphate shunt)

It is an alternative route for the metabolism of glucose where it primarily deals with the generation of reducing power in the form of reduced nicotinamide adenine dinucleotide phosphate (NADPH) which is used in the reductive biosynthesis of steroid, amino acids, fatty acids, nucleotides and provide a mechanism for the metabolic utilization of five carbon (5C) sugars (e.g., ribose, ribulose) ingested in foods. The reactions of the pathway are divided into two phases, namely, oxidative non-reversible phase and non-oxidative reversible phase. The generated NADPH also keeps glutathione in the reduced state which helps in mopping up free radicals.

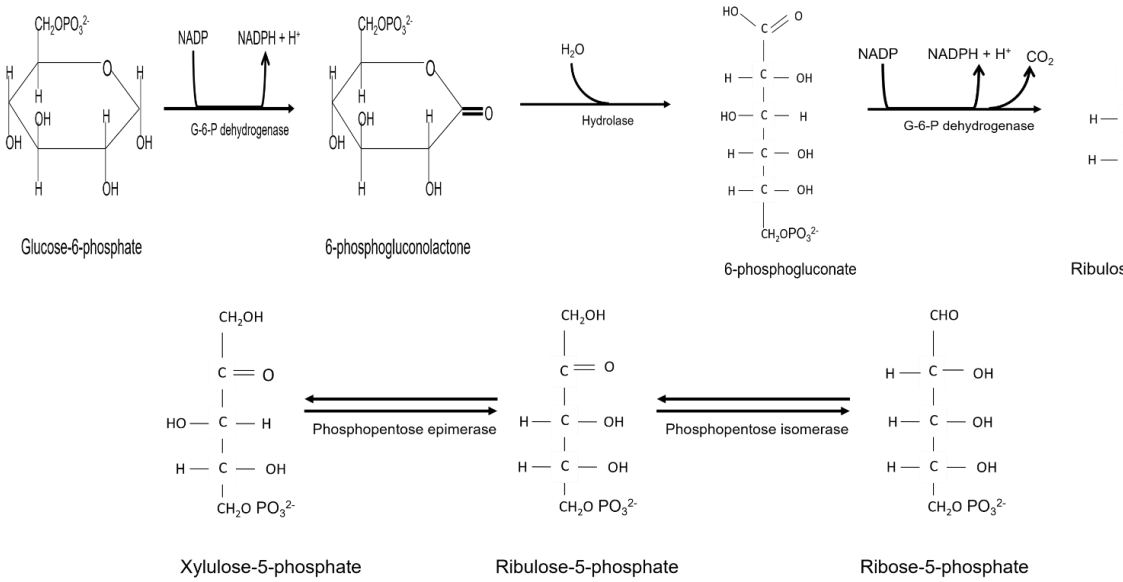

Figure 5: The Pentose Phosphate Pathway

Electron transport chain (ETC) and oxidative phosphorylation

Electron transport chain is also called the respiratory chain. It is a process that couples the oxidative degradation of carbohydrates, fats, and proteins to the synthesis of ATP. It operates inside the inner

membrane of the mitochondria. Oxidative phosphorylation is the coupling of oxidation with phosphorylation. It involves a series of electron donor/acceptor (NAD^+/NADH, FAD/$FADH_2$) molecules. These reactions couple glycolysis and Krebs cycle for the purposes of generating ATP. The electron acceptors/donors are reduced when receiving electrons and are oxidized when losing electrons to one another on electrochemical gradient. Each molecule in the series has a lower redox potential than the one before it. The electrons flow from the more electronegative components to the more electropositive ones. When electrons are transferred, energy is lost, and cells can utilize this energy to do cellular work such as synthesis of ATP. The major force or power driving these reactions is the Gibbs free energy of the reactants and products. This is the energy available to do work.

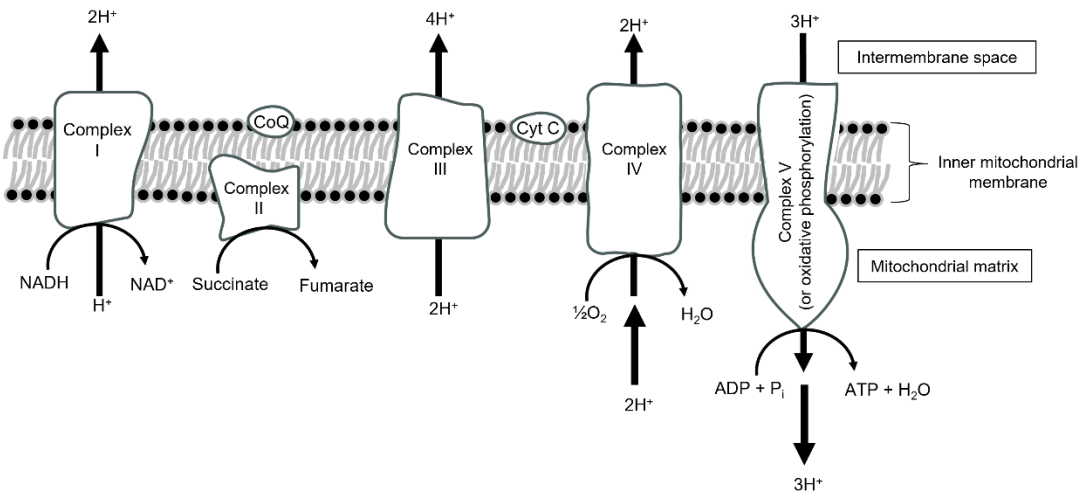

Figure 6. Electron Transport Chain and Oxidative Phosphorylation

Organization of electron transport chain (Respiratory chain)

Electrons are transferred from a reduced equivalent (NADH and FADH) to oxygen through a series of membrane bound carriers or complexes. A good number of these carriers are integral membrane proteins that

are grouped as complex I, complex II, complex III and IV. Other important components of this system are coenzyme Q (CoQ) and cytochrome c (Cyt C). Within each complex, electrons are passed through the electron carriers.

Complex I (NADH dehydrogenase or NADH-CoQ reductase: This complex catalyzes the oxidation of NADH leading to reduction of CoQ.

$NADH + H^+ + Q \longrightarrow NAD^+ + QH_2$

This process starts with the prosthetic group, FMN accepting 2e- from NADH and passing them to the coenzyme Q through the Fe-S. This can be represented as follows:

$NADH + FMN + H^+ \longrightarrow NAD^+ + FMNH_2$

$FMNH_2 + Fe\text{-}S\ (oxidized) \longrightarrow FMNH^{:} + Fe\text{-}S\ (reduced) + H^+.$

The latter passes its electron to the next iron-sulfur center in the pathway and becomes reoxidized. It is now ready to pick the second electron from the $FMNH^{:}$

$FMNH^{:} + Fe\text{-}S\ (oxidized) \longrightarrow FMN + H^+ + Fe\text{-}S\ (reduced).$

Electrons pass through a number of iron-sulfur centers and are finally transferred to the coenzyme Q. The latter accepts $2e^-$ and $2H^+$ to yield the fully reduced QH_2. The free energy released during this process is utilized to drive 4 protons out of the mitochondrial matrix to the intermembrane space. In effect, this complex act as a proton pump.

Complex II (Succinate dehydrogenase)

FAD is the initial electron acceptor and is reduced to $FADH_2$ during the oxidation of succinate to

fumarate in the TCA cycle. Other major enzyme systems that transfer their electrons to complex II are fatty acyl-CoA dehydrogenase and mitochondrial glycerol phosphate dehydrogenase. $FADH_2$ is reoxidized by transfer of electrons to coenzyme Q through three iron-sulfur centers. The coenzyme Q is fully reduced to QH2. The latter is reoxidized through complex III.

$FADH \longrightarrow Fe\text{-}S_{(1)} \longrightarrow Fe\text{-}S_{(2)}\ \ Fe\text{-}S_{(3)} \longrightarrow QH_2 \longrightarrow$

The free energy generated in this complex is not enough to pump protons into the inter membrane space. So, this does not act as a proton pump.

Complex III (Cytochrome bc1 complex or Cytochrome Reductase)

This is an aggregation of iron-sulfur proteins, cytochrome b and cytochrome c1. Both contain heme prosthetic groups. This complex accepts electrons from $CoQH_2$. These electrons are generated by electron transfer from complexes I and II. During transfer of electrons, the iron in the heme group changes from Fe^{3+} to Fe^{2+} states. The free energy released during this process is utilized to drive 4 protons out of the mitochondrial matrix to the intermembrane space. This complex acts as a proton pump just like complex I and IV.

Cytochrome IV (Cytochrome Oxidase)

It is in this complex that oxygen accepts all the electrons transferred from $NADH/FADH_2$ through complexes I, II and III. The reaction is represented below.

$$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$$

Cytochrome oxidase contains two heme groups, cytochrome a and cytochrome a3 and copper ions, CuA and CuB. The functional unit of the enzyme is referred to as a-a3. This cytochrome reduces cytochrome c that donates electrons to complex IV. The four electrons are transferred into the complex one at a time. Here, two electrons are pumped into the intermembrane space.

Proton pump and ATP synthesis

Complexes I, III and IV pump H^+ from the matrix (inside) to the inter membrane space (outside). This creates a high concentration of H^+ outside the inner membrane. The outside is more positive than the inside. The pH is also lower on the outside than the inside. This causes H^+ to enter into the mitochondria through the channels Fo. This proton influx causes ATP synthesis by ATP synthase.

Electron transport inhibitors

Some inhibitors of specific electron carriers are known. They include the following:

Rotenone and **amytal**: they inhibit electron transport at NADH dehydrogenase thereby preventing NADH oxidation. This does not affect the oxidation of $FADH_2$ since this feeds electrons into the chain at CoQ.

Antimycin A: inhibits electron transport at the cytochrome bc1 complex

Cyanide (CN), **azide** (N^-_3) and **carbon monoxide** (CO) all inhibit cytochrome oxidase.

Coupling and respiratory control

Electron transport is coupled to ATP synthesis. In essence electrons do not flow through the electron transport chain to oxygen unless ADP is simultaneously phosphorylated to ATP. In the presence of ADP, electron transport proceeds and ATP is made. Decrease in the concentration of ADP slows down the electron transport. This process ensures that electron flow occurs only when ATP synthesis is required.

Uncouplers: These are agents when added to cells stop ATP synthesis but allow electron transport to go on. Oxygen is still consumed. One example is 2,4-dinitrophenol (DNP). These agents are able to bind H^+ ions and transport them across the membrane. The same agent carries H^+ ions back into the mitochondria, preventing the formation of proton gradients. Therefore, ATP cannot be formed by oxidative phosphorylation.

Chemistry of amino acids and proteins

Proteins are the main building blocks of cells, tissue, organs, and systems and eventually an animal. The basic building blocks of proteins are amino acids. These amino acids bond together via peptide bonds to form larger protein molecules.

Basic structure of amino acids

Amino acids are composed of amino group (-NH2), carboxylic group (-COOH) and R-side chain.

Naming and classification of amino acids

Amino acids are named/designated with a three or one letter abbreviation for ease of identification e.g., the first 20 amino acids are Alanine (Ala, A), Arginine (Arg, R), Asparagine (Asn, N), Aspartic acid (Asp, D), Cysteine (Cys, C), Glutamic acid (Glu, E), Glutamine (Gln, Q), Glycine (Gly, G), Histidine (His, H), Isoleucine (Ile, I), Leucine (Leu, L.), Lysine (Lys, K), Methionine (Met, M), Phenylalanine (Phe, F), Proline (Pro, P), Serine (Ser, S), Threonine (Thr, T), Tryptophan (Trp, W), Tyrosine (Tyr, Y) and Valine (Val, V). Amino Acid can be classified based on their structure (and/or structure of side chains i.e., R-chains), their incorporation in proteins, position of the amino group, acid-base properties, biological importance etc. Aliphatic amino acids (amino acids with alkyl side chain) e.g., Ala, Val, Met, Leu and Ile. Aromatic Amino Acids (with aromatic ring side chain e.g., Phe, Tyr and Trp. Hydroxy Amino Acids (with -OH group) e.g., Ser and Thr). Sulphur containing Amino Acids (with S in the side chain) e.g., Cys and Met. Dicarboxylic Amino Acids (with extra carboxylic group in the side chain) e.g., Asp and Glu. Diamino Acid (with extra amino group in the side chain) e.g., Lys. Branched Amino Acids (amino acids with a branched alkyl group) eg., Leu, Ile, Val. Other classifications are non-polar amino acids (e.g., Gly, Val, Met etc.) and polar amino acids (e.g., Asp and Glu).

Table 1: The First Twenty Amino Acids

Name	Three Letter Code	One Letter Code	Molecular Weight	Molecular Formula
Alanine	Ala	A	89.1	$C_3H_7NO_2$
Arginine	Arg	R	174.2	$C_6H_{14}N_4O_2$
Asparagine	Asn	N	132.1	$C_4H_8N_2O_3$
Aspartic acid	Asp	D	133.1	$C_4H_7NO_4$
Cysteine	Cys	C	121.2	$C_3H_7NO_2S$
Glutamic acid	Glu	E	147.1	$C_5H_9NO_4$
Glutamine	Gln	Q	146.2	$C_5H_{10}N_2O_3$
Glycine	Gly	G	75.1	$C_2H_5NO_2$
Histidine	His	H	155.2	$C_6H_9N_3O_2$
Isoleucine	Ile	I	131.2	$C_6H_{13}NO_2$
Leucine	Leu	L	131.2	$C_6H_{13}NO_2$
Lysine	Lys	K	146.2	$C_6H_{14}N_2O_2$
Methionine	Met	M	149.2	$C_5H_{11}NO_2S$
Phenylalanine	Phe	F	165.2	$C_9H_{11}NO_2$
Proline	Pro	P	115.1	$C_5H_9NO_2$
Serine	Ser	S	105.1	$C_3H_7NO_3$
Threonine	Thr	T	119.1	$C_4H_9NO_3$
Tryptophan	Trp	W	204.2	$C_{11}H_{12}N_2O_2$
Tyrosine	Tyr	Y	181.2	$C_9H_{11}NO_3$
Valine	Val	V	117.2	$C_5H_{11}NO_2$

Other unusual classification based on position of amino group on the carbon chains e.g., α, β, γ, δ amino acids seen in β-alanine of vitamin

B5 and co-enzyme A and δ-aminobutyric acid a neurotransmitter in the brain. Classification based on biological function as in essential and non-essential amino acids. Essential amino acids cannot be synthesized by the body, and it has to be acquired through food. On the other hand, non-essential amino acids are called so because they can be synthesized by the body. There are nine essential amino acids (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine) and eleven non-essential amino acids (alanine, arginine, asparagine, aspartic acid, cysteine, glutamic acid, glutamine, glycine, proline, serine, and tyrosine). Cells in the body can provide the carbon skeleton of the nonessential amino acids. These carbon skeletons come from intermediates of the glycolytic pathway and from intermediates in the Citric Acid Cycle (Tricarboxylic Acid Cycle or the Krebs Cycle). Nonessential amino acids can be formed from 3-phosphoglycerate (or 3-phosphoglyceric acid), pyruvate (or pyruvic acid), oxaloacetate (or oxaloacetic acid), and α-ketoglutarate (or α-ketoglutaric acid).
There is also another classification based on metabolism as glucogenic (e.g., Gly, Ala, Ser, Asp, Asn, Glu, Gln, Pro, Val, Met, Cys, His and Arg) and ketogenic amino acids (e.g., Leu and Lys).

Properties of Amino Acids

Amino acids possess the following physical and chemical properties: optical activity, solid, tasteless, soluble in polar solvents, high melting points, form zwitterion, undergo transamination reactions, oxidative deamination, esterification, transmethylation reactions, formation of sulfhydryl and peptide bonds. Other reactions include Ninhydrin reaction, Million's reaction, Sakaguchi's, Biuret and Xanthoproteic reactions etc.

Amino acid metabolism

Amino acids could be glycogenic, ketogenic, or mixed. Most amino acid carbon skeletons are degraded to intermediates of the Krebs cycle after transamination. As a result, they can increase the blood glucose levels via the gluconeogenic pathway and are known as "glycogenic" amino

acids. Alanine is made from and degraded to pyruvate; Arginine is made from and degraded to glutamate; Asparagine is made from and degraded to aspartate; Aspartate is made from and degraded to oxaloacetate; Cysteine can be made from methionine and degraded to pyruvate; Glutamate is made from and degraded to oxoglutarate; Glutamine is made from and degraded to glutamate; Histidine can be degraded to glutamate; Methionine can be degraded to propionyl-CoA; Proline is made from and degraded to glutamate; Serine is made from phosphoglycerate and degraded to pyruvate and Valine can be degraded to propionyl-CoA. "Ketogenic" amino acids tend to worsen diabetic ketoacidosis and are typically degraded to acetoacetate or acetyl-CoA. Leucine is an example of this type, which is an essential amino acid that can be degraded to acetyl-CoA. "Mixed" amino acids can be degraded both to amino acids of the Krebs cycle and to acetyl-CoA, with characteristics of both glycogenic and ketogenic amino acids. Isoleucine can be degraded to acetyl-CoA and propionyl-CoA; Phenylalanine is degraded to tyrosine while Tyrosine can be made from phenylalanine and degraded to fumarate and acetoacetate.

Classification, structure, and functions of proteins

Amino acids act as the building blocks of proteins. Amino acids are found as dipolar ions in solutions. The charged properties result from the presence of amino and carboxyl groups and lead to solubility in water, an ability to act as electrolytes, a crystalline appearance and high melting points. They form peptide bonds via a condensation reaction and the elimination of water in a process that normally occurs on the ribosomes. The formation of one peptide bond covalently links two amino acids forming a dipeptide. Polypeptides or proteins are built up by the repetitive formation of peptide bonds and an average sized protein may contain 1000 peptide bonds. The side chains dictate the chemical and physical properties of proteins. Side chain properties include charge, hydrophobicity and polarity and underpin many aspects of the structure and function of proteins.

Structure of proteins: This includes the primary, secondary, tertiary, and quaternary structures. The primary structure of proteins involves the linear sequence or order in which the amino acids are linked together while the secondary structure entails the arrangement in space of the atoms in the backbone of the polypeptide chain. The three basic units of secondary structure are the α helix, the β strand and turns. Note that the conformations of the side chains of the amino acids are not part of the secondary structure. Tertiary structure of proteins is the three-dimensional arrangement of all the atoms in a protein, including those in the side chain and in any prosthetic group. Disulfide bonds formation between cysteine residues, located on either the same or different peptide chains, are the major tertiary structure determinants. Hydrophobic interactions between nonpolar amino acid residues in a protein contribute to stabilizing the tertiary protein structure. Quaternary structure is a property of proteins that consist of more than one polypeptide chain, also referred to as subunits, which are linked by non-covalent bonds. The number of chains can range from two to more than a dozen, and the chains may be identical or different. Commonly occurring examples include dimers, trimmers, tetramers. Other classifications like Fibrous proteins (e.g., collagen, tendons), Globular proteins (albumin, globulin, protamine) and Conjugated proteins (nucleoproteins, lipoproteins, glycoproteins, flavoproteins, metalloproteins) exist. Proteins are also classified based on their biological functions as Enzymes, Transport proteins (lipoproteins), Antibodies and Hormones.

Functions of proteins

- Proteins function as enzymes or catalytic proteins e.g DNA polymerases and ligase;
- Contractile proteins: Actin, Myosin, Tubulin, Dynein.
- Structural or cytoskeletal proteins: Tropocollagen, Keratin.
- Transport proteins: Haemoglobin, Myoglobin, Serum albumin, Ceruloplasmin,

- Transthyretin; Effector proteins: Insulin, Epidermal growth factor, Thyroid stimulating hormone; Defence proteins: Ricin, Immunoglobulins, Venoms and Toxins, Thrombin.
- Electron transfer proteins: Cytochrome oxidase, Bacterial photosynthetic reaction centre, Plastocyanin, Ferredoxin; Receptors: CD4, Acetycholine receptor.
- Repressor proteins: Jun, Fos, Cro, Chaperones, Storage proteins: Ferritin and Gliadin.

Urea cycle and its biochemical importance

Urea biosynthesis starts with condensation of ammonium ion and carbon dioxide.

Condensation of carbon dioxide and ammonium to form carbamoyl phosphate is catalyzed by an enzyme called carbamoyl phosphate synthase I which is activated by N-acetyl-glutamate (allosteric activator). This reaction requires 2 moles of ATP. This ATP provides the driving force for the synthesis of the amide bond and the mixed acid anhydride bond of carbamoyl phosphate. Binding of N-acetyl-glutamate induces a conformational change that enhances the affinity of the synthase for ATP. Carbamoyl phosphate synthase I is the rate limiting or pacemaker enzyme of urea cycle.

The second step which also occurs in the mitochondrial matrix of the hepatocytes involves the enzymatic combination of L-ornithine and carbamoyl phosphate to produce L-citrulline. In this reaction, L-ornithine transcarbamoylase transfers carbamoyl phosphate to ornithine, forming citrulline and orthophosphate. NB: entry of ornithine into mitochondrial matrix and exodus of citrulline into the cytosol involve mitochondrial inner membrane transport system.

The third step reaction in the urea cycle occurs in the hepatocyte cytosol. Here, aspartate (which may result from transamination of oxaloacetic acid from TCA cycle) is linked with citrulline via the amino group of aspartates to produce argininosuccinate by the enzyme argininosuccinate synthase or argininosuccinic acid synthase. This enzymatic linkage requires energy in the form of ATP.

NB: the amino group of the aspartate provides the second nitrogen of urea.

Non-hydrolytic cleavage of argininosuccinate by the enzyme argininosuccinase or argininosuccinate lyase produces arginine and fumarate. This reversible trans-elimination reaction retains nitrogen in the product arginine and releases the aspartate skeleton as fumarate. While arginine continues with the cycle, fumarate is hydrolysed to form malate by fumarase, and malate dehydrogenase catalyzes formation of oxaloacetate from malate. Oxaloacetate undergoes transamination with glutamate to reform aspartate. Carbon skeletons of aspartate and fumarate act as carrier transporter for transport of the nitrogen of glutamate into a precursor of urea

Finally, arginine is hydrolyzed (cleaved) to form urea and reform ornithine. Arginase catalyses this reaction. Ornithine goes into the urea cycle again while urea is eliminated. Urea cycle is also called ornithine cycle for this reason.

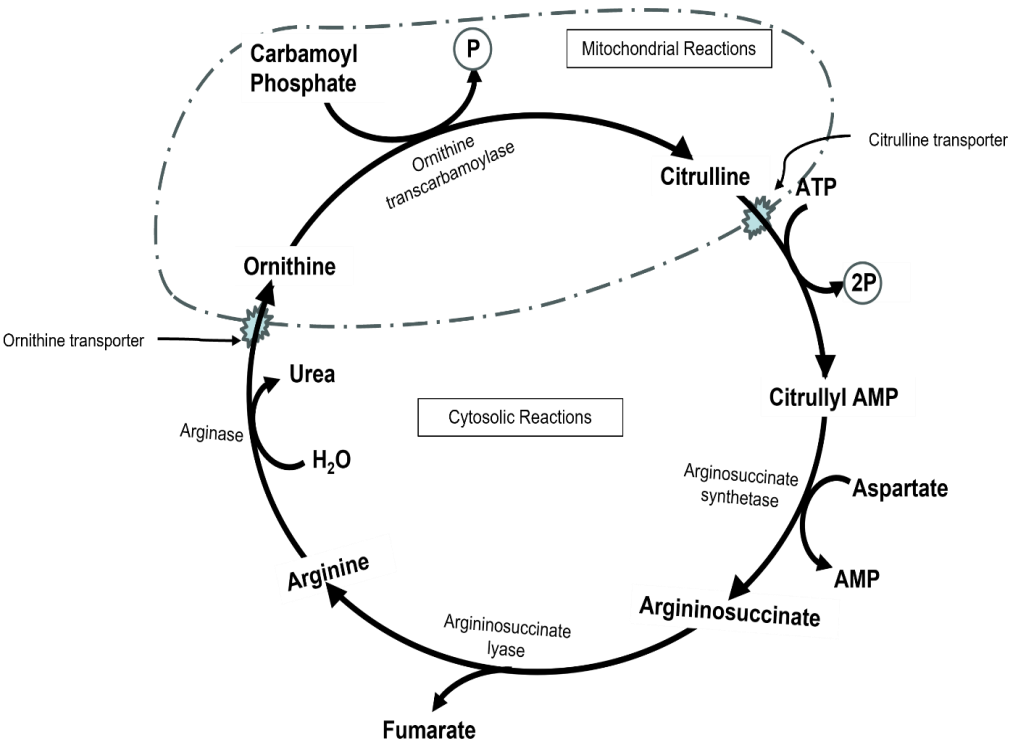

Fig. 7: The Urea Cycle

NB: there is no net gain or loss of ornithine, citrulline, argininosuccinate or arginine. Carbon dioxide, ammonium, ATP, and aspartate are however consumed.

All defects in urea biosynthesis result in ammonia intoxication since urea synthesis converts toxic ammonia to non-toxic urea. This intoxication is more severe when the metabolic block occurs at steps one and two, since some covalent linking of ammonia to carbon has already occurred. Severe deficiency or total absence of the activity of any of the first four enzymes in the pathway (CPS1, OTC, ASS1, ASL) and a cofactor NAG result in accumulation of ammonia and other precursor metabolites during the first few days of life. Hyperammonemia type 1: this results from deficiency of CPS 1 while hyperammonemia type 2 is occasioned

by deficiency of OTC. It is an X-linked chromosomal deficiency. This has been reported in Adult German Shepherd dog. Citrullinemia results from argininosuccinate synthase deficiency. Argininosuccinic aciduria is characterized by elevated levels of argininosuccinate in the blood, CSF, and urine. It is caused by lack or absence of argininosuccinase.

Glucose-6-phosphate dehydrogenase (G6PD) deficiency

Glucose-6-phosphate dehydrogenase removes hydrogen (oxidation) from glucose-6-phosphate to produce phosphogluconolactone, thereby reducing $NADP^+$ to NADPH in the pentose phosphate pathway. The NADPH generated is essential because it helps to maintain the level of reduced glutathione (GSH), a master antioxidant which protects the red blood cell membrane as follows: Sulfhydryl (SH) of haemoglobins is oxidized by free radicals (superoxide ions, hydrogen peroxides) to form disulfide bridges (S-S) leading to reduced solubility of haemoglobin and consequent precipitation and formation of Heinz bodies. Glutathione peroxide has the responsibility of re-converting the S-S to SH during which it (Glutathione peroxidase) is oxidized to GSSH (oxidized glutathione) but ultimately will be restored to GSH (reduced glutathione) by glutathione reductase. This last reaction requires NADPH. Recall that NADPH formation requires the enzyme Glucose-6-phosphate dehydrogenase. Therefore Glucose-6-phosphate dehydrogenase deficiency will lead to elevated oxidative damage to the red blood cells, enhanced Heinz body formation, increased RBC membrane permeability and lysis leading to haemolytic anaemia. Glucose-6-phosphate dehydrogenase deficiency is an x-linked inherited disorder. It has been reported in dogs.

Inborn errors of metabolism of some amino acids,

Inborn errors of metabolism (IEM) include a group of disorders in which a single gene defect causes a clinically significant block in a metabolic pathway culminating in accumulation of the substrate or deficiency of the product. Problems occur due to accumulation of substances which are toxic or interfere with normal function. Inborn errors can occur in all nutrients including amino acids. Some inborn errors of amino

acids include Phenylketonuria, Alkaptonuria, Albinism, Cystinuria, Primary Hyperoxaluria, Homocystinuria, Maple syrup urine disease, Histidinaemia, Hartnup disease etc.

Phenylketonuria: It is an inborn error that results in reduced metabolism of Phenylalanine (an amino acid) due to a disorder in phenylhydroxylase gene (PAH gene). Phenylalanine hydroxylase is an enzyme that catalyzes hydroxylation of the aromatic side chain of phenylalanine to generate tyrosine. Defect in PAH gene results in buildup of phenylalanine to a toxic level. Phenylketonuria is an autosomal recessive disorder.

Alkaptonuria: It is an inherited disorder leading to error in homogentisate metabolism. Homogentisate 1,2 dioxygenase catalyzes the conversion of homogentisate to 4-maleylacetoacetate. A mutation in the homogentisate 1,2 dioxygenase gene (HGD gene) results in accumulation of homogentisic acid and alkapton (oxidized form of homogentisic acid) which are excreted in urine giving it an unusually dark colour.

Albinism: This is an autosomal recessive disorder that leads to a complete (Tyrosinase-negative) or partial (Tyrosinase-positive) absence of melanin pigment (which is synthesized by melanocytes and from tyrosine) in the eye, skin (oculocutaneous albinism) and hair. Tyrosinase is an enzyme that catalyzes an important step in the synthesis of melanin. The biochemical defect responsible for oculocutaneous albinism type 1is the deficiency of tyrosinase which converts tyrosine to DOPA (a step in the formation of melanin). Tyrosinase deficiency is due to a mutation in the TYR gene, which directs tyrosinase synthesis. Complete (tyrosinase-negative) is characterized by photophobia, Nystagmus, Strabismus and decreased visual acuity. Albinism has been noted in Iceland sheep, shorthorn cattle. It has also been reported in birds, reptiles, and amphibians.

Cystinuria: Cystinuria is an autosomal recessive inherited disorder leading to cystine kidney stones due to a defection in a transport protein complex responsible for reabsorbing cystine and other dibasic amino acids from the proximal convoluted tubule into the systemic circulation. A mutation in SLC3A1 (Solute Carrier family 3 member1) and SLC7A9 (Solute Carrier family 7 member9) genes disrupts the function of this transport protein leading to increased urine cystine level which would ultimately precipitate out as stones. Cystinuria has been reported in dogs.

Homocystinuria: This autosomal recessive trait results from the inability of the body to process or metabolize methionine owing to the deficiency of the enzyme, cystathionine beta synthase. This leads to accumulation of homocysteine and methionine in the biologic fluid and ultimately excreting high amount of homocysteine in urine. Deficiencies of pyridoxine, vitamin B12 and folic acid have been implicated in homocystinuria. Cystathionine beta synthase converts homocysteine to cystathionine using pyridoxal phosphate as a cofactor in a transsulfuration pathway.

Histidinemia: This inborn error in the metabolism of histidine is occasioned by deficiency of the enzyme histidase (or Histidine ammonia-lyase). Histidase converts histidine into ammonia and urocanic acid. A defection in the HAL gene either renders histidine ammonia-lyase inactive or significantly reduces its activity. This leads to increased levels of histidine in the blood. Histidinemia has been modeled in rats and mice.

Maple Syrup Urine Disease (MSUD): Maple Syrup Urine Disease, an autosomal recessive condition occurs due to error in the metabolism of branched chain amino acids (leucine, isoleucine, valine) due to the deficiency of branched-chain alpha-keto acid dehydrogenase, an enzyme encoded by BCKDHA, BCKDHB, DBT and DLD genes. Mutation in the genes leads to a defective synthesis of the branched-chain alpha-keto acid dehydrogenase and the attendant accumulation of the

branched chain amino acids and their toxic by-products (keto acids) which are secreted in the urine with characteristic Maple syrup odour.

Hartnup disease (Pellagra-like dermatosis): It is an inborn error in the absorption of the amino acid, tryptophan (a non-polar amino acid) due to a defective transport protein (sodium-dependent and chloride-independent neutral amino acid transporter) which is mainly expressed in the kidney and intestine. This will lead to excessive loss of tryptophan from malabsorption. Tryptophan can be converted to Niacin, a precursor of nicotinamide, an important constituent of NAD^+. Mutation in the gene, SLC6A19 has been fingered as the causative agent of defection in the transport protein.

Structure, properties, biochemical functions of haemoglobin, Porphyrins, Porphynurias, functions of bile pigments, biochemistry of jaundice

Haemoglobin (Hb) is more than 90% of proteins within erythrocytes and it contains 0.34% iron by weight. It is a tetrameric protein consisting of four polypeptide globin chains, each of which contains a haeme prosthetic group. Haeme is a planar molecule composed of tetrapyrrole protoporphyrin IX, containing a central iron ion. A Hb tetramer is capable of binding four molecules of oxygen when fully saturated. To bind oxygen, iron ions within heme molecules must be in the Fe^{2+} state. Methemoglobin is formed when iron is oxidized to the Fe^{3+} state. Hb plays important functions in oxygen transport, carbon dioxide transport, and buffering of hydrogen ions.

The normal haemoglobin level in domestic animals are Cattle: 11.23 g/100ml; Buffalo: 12.9 g/100ml; Horse: 11.5 g/100ml; Goat: 10.9 g/100ml; Sheep: 14.4 g/100ml; Pig: 11.0 g/100ml; Dog: 13.0 g/100ml; Cat: 12.0 g/100ml. Because the erythrocytes are larger, red blood cell numbers are lower in birds compared with mammals. Numbers of RBCs also tend to be lower in young birds and females. Mature red cells in birds are large oval cells that contain oval nuclei. Immature red cells are rounder, have less oval to round nuclei,

and polychromatophilic cytoplasm. Polychromatophilic red cells are fairly numerous in some avian species in the absence of anaemia.

Structure of the Porphyrins

The parent nucleus of the porphyrins is a cyclic tetrapyrrole, which consists of four pyrrole nuclei with their α (adjacent to the β) carbon atoms linked together by methane (-C) bridges. This compound is called porphin. The various synthetic and naturally occurring porphyrins are derivatives of porphin, distinguished from each other by the type and position of the radicals substituted for the hydrogen atoms at positions 1 through 8.

Porphyrias in Animals

The term porphyria is used to define those disease states that have a hereditary basis and increased urinary or fecal excretion of uroporphyrins and coproporphyrins. Depending on the fundamental biochemical defect, the porphyrias can be broadly classified based on their tissue of origin, the erythropoietic system, or the liver. The term porphyrinuria is used to define those acquired conditions in which the principal, if not the sole, porphyrins being excreted are the coproporphyrins. There are different classes of porphyrias in animals. They are: Erythropoietic Porphyrias; under this we have the following:

Bovine Congenital Erythropoietic Porphyria: One of the characteristic findings in bovine congenital erythropoietic porphyria (CEP) is a reddish-brown discoloration of the teeth and bones. Discolorations of this type have been observed in cattle at slaughter and these cattle are presumed to have had the disease. The predominant symptoms of teeth and urine discoloration and the photosensitization of the severely affected animal are readily apparent, and a tentative diagnosis can be confirmed by the orange-red fluorescence of the teeth and urine when examined with near ultraviolet light or a Woods lamp.

Bovine Erythropoietic Protoporphyria: This disorder of porphyrin metabolism occurs in humans and in cattle. Erythropoietic

protoporphyria (EPP) is inherited as a dominant autosomal trait and patients do not have the major signs of CEP such as anemia, porphyrinuria, or discolored teeth. Photosensitivity of the skin is the only significant clinical manifestation of the disease.

Porphyria of Swine is inherited as a simple autosomal dominant trait, except for the very severe cases, there appears to be little or no effect on the general health of the pig. Photosensitivity is not seen even in the white pigs. The predominant feature in the affected pig is a characteristic reddish discoloration of the teeth, which fluoresces on exposure to ultraviolet light. Porphyrin deposition in the teeth of the newborn pig is virtually pathognomonic of porphyria in swine.

Porphyria of Cats has the following clinical signs; kitten's teeth were brown and fluoresce red under ultraviolet light. Its urine was amber colored and was qualitatively positive for uroporphyrin, coproporphyrin, and porphobilinogen. There was no evidence of anemia or photosensitization. The inheritance of the porphyria in these cats is a simple autosomal dominant trait analogous to that seen in swine.

Normal Porphyrias: All fox squirrels (*Sciurus niger*) have red bones caused by the accumulation of URO I and COPRO I. The fox squirrel porphyria resembles the CEP of humans, cows, and cats by having a deficiency of UROgenIII-Cosyn, type I porphyrins in their urine and faeces, and discolored bones, teeth, and tissues, which fluoresce on exposure to ultraviolet light. There is increased erythropoiesis but no apparent hemolytic anemia, no photosensitivity, or any other clinically deleterious effects. These relatively benign effects are most likely due to their thick hair coats and nocturnal living habits. It is interesting that an enzyme deficiency with serious health effects in other animals should have evolved as a "normal" characteristic in the fox squirrel.

Functions of Bile pigments; Jaundice

Bile pigments are the coloured compounds, which are broken down products of the haemoglobin. The bile pigments are bilirubin and its

oxidized form, biliverdin. Mixed with the intestinal contents, they give the brown colour to the faeces. Bilirubin is a yellowish pigment found in bile, and is a fluid produced by the liver and stored in the gallbladder and is excreted in bile. The liver also excretes bilirubin. Bile pigments are potent in vitro scavengers of free radicals and they are an important inducible antioxidant system that protects against various cellular stresses including oxidative damage. Bilirubin is a pigment that is produced by the degradation of the heme portion of haemoglobin and myoglobin and, to a smaller extent, non-heme porphyrins. Birds lack biliverdin reductase and do not form significant quantities of bilirubin. Bilirubin is metabolized to urobilinogen by bacteria in the intestine. This can be reabsorbed and excreted in urine. Urine urobilinogen may be increased with increased bilirubin delivery to the GI tract (hemolytic disease) or decreased absent in patients with biliary obstruction or intestinal malabsorption.
Bile has the following functions: it aids in the digestion of fat via fat emulsification; its involved in absorption of fat and fat-soluble vitamins; excretion of bilirubin and excess cholesterol and the bile provides an alkaline fluid in the duodenum to neutralize the acidic pH of the chyme that comes from the stomach. In summary, bile carries away waste and it breaks down fat during digestion.

Types of bilirubin: (i) Unconjugated bilirubin, which is not water soluble and is transported in the blood bound to albumin by an ionic bond. (ii) Conjugated bilirubin is dissociated from albumin at the hepatocyte cell membrane and taken into the hepatocyte by plasma membrane transporters. Conjugated bilirubin is formed in the hepatocyte by glucuronidation, which renders the molecule water soluble.
Hyperbilirubinemia, an increased serum concentration of bilirubin, may cause visible discoloration of tissues or body fluids (skin, sclera, gingival, serum, etc.), a condition called icterus or jaundice. Causes of hyperbilirubinemia include the following: (a). Increased bilirubin production (pre-hepatic hyperbilirubinemia). (i) Increased erythrocyte breakdown with hemolytic disease or following internal hemorrhage

causes increased bilirubin production. (ii) The resulting increase in bilirubin concentration overwhelms hepatic uptake, conjugation, and/or secretion capacities.
(b). Decreased hepatic uptake or conjugation (hepatic hyperbilirubinemia), (i) Loss of hepatic function results in decreased capacity for bilirubin uptake and conjugation. (ii) Anorexia or fasting in horses decreases bilirubin uptake by hepatocytes. Total bilirubin concentration may reach 10 mg/dL in otherwise healthy horses. (iii) Sepsis may decrease bilirubin uptake.
Bilirubinuria, conjugated bilirubin passes through the glomerular filter into the urine. Unconjugated bilirubin and biliprotein are albumin bound. This molecular complex is too large to pass through the normal glomerular filter. Canine renal tubular epithelial cells have a limited ability to conjugate and excrete bilirubin into the urine. Healthy dogs, especially males, therefore, often have trace bilirubinuria with concentrated urine.
With marked bilirubinuria, bilirubin crystals may appear in the urine sediment. Post-hepatic biliary obstruction is expected to increase conjugated bilirubin concentration, but hepatic injury secondary to cholestasis also may result in increased concentration of unconjugated bilirubin. Dogs and cats with pre-hepatic or post-hepatic hyperbilirubinemia often have a mixture of conjugated and unconjugated bilirubin.
Birds lack biliverdin reductase and form biliverdin instead of bilirubin as the primary breakdown product of heme. Biliverdinemia is rare in birds; however, green, bile-stained urates may be observed in the feces during liver disease.

Hemoglobinopathies

Hemoglobinopathy is the alteration in the biologic function of hemoglobin consequent upon its abnormal synthesis**.** The abnormalities can be as a result of abnormality in the structure of one of the globin chains or deficiency. Any of these forms of mutations in the globin synthesis can result in the abnormality in function of the resulting hemoglobin. These abnormalities may be alterations in: a) The solubility

of hemoglobin; b) The stability of hemoglobin; c) The oxygen carrying capacity of the blood; d) The rate of hemoglobin production.

Sickle cell disease: This is one of the commonest hemoglobinopathies which result from impaired solubility of hemoglobin. In sickle cell haemoglobin (Hb^S), valine (valyl residue) replaces glutamate residue at position six (6) of the beta chain, located on the surface of the hemoglobin, exposed to water. This substitution replaces the polar glutamate residue with a nonpolar one and generates a 'sticky patch' on the surface of β –chain. This is present on both $OxyHb^S$ and $deoxyHb^S$ but not in oxy or deoxy Hb^A. On the surface of deoxygenated Hb, there exists a complement to the sticky patch, but in oxygenated Hb, this complementary site is masked.
NB: The sickle cell red blood cells are more fragile than their normal Hb^A RBC counterparts. The deoxyHb form of Hb^S tends to aggregate and precipitate out of solution. In sickle RBC, hemolysis is very common. Other mutant variants of hemoglobins include HbC and HbE. In hemoglobin C, glutamic acid is replaced by lysin at position 6 of the beta chain while glutamic acid is replaced by lysine at position 26 of the beta chain in hemoglobin E. Heinz body is formed when denatured and precipitated haemoglobin attach on the inner surface of red blood cell membrane,

Thalassemias: These result from reduced synthesis of the α or β polypeptides (α – thalassemias or β – thalassemias respectively). In β–thalassemias, there is a compensatory increase in the production of HbA_2 and Hb-F neither of which contains β–chains. α – thalassemias is rarer. It presents at birth because HbF synthesis is affected as well as HbA.

Methemoglobinemia (hb^{-m}): Here, the heme iron is ferric not ferrous. Heme is stabilized in the ferric (Fe^{3+}) state since it forms a tight ionic complex with the phenolate anion of tyrosine. Fe^{3+} can be acquired by oxidation of Fe^{2+} to Fe^{3+} by agents such as sulfonamides. It can also be inherited owing to the presence of Hb^M or due to decreased activity

of methemoglobin reductase, an enzyme that reduces the Fe^{3+} of methemoglobin to Fe^{2+}. Since methemoglobin does not bind oxygen, it cannot participate in oxygen transport. Oxygen affinity is reduced, and the Bohr effect is absent in α–chain hemoglobin M variant because the R-T equilibrum favours the T form. In hemoglobin M, tyrosine replaces histidine F8.

Glycosylated hemoglobin (HbA_{1c}): Hemoglobin is non – enzymatically glycosylated when blood glucose enters the erythrocytes. HbA_{1c} may be separated from HbA by ion exchange chromatography or electrophoresis. The fraction of glycosylated Hb, normally about 5% is proportionate to blood glucose concentration. Measurement of HbA_{1c} thus provides information useful for the management of *Diabetes mellitus*. The level of HbA_{1c} reflects the average blood glucose concentration over the preceding 6-8 weeks.

Summary

Carbohydrates are defined as polyhydroxy aldehydes or ketones or compounds that can be hydrolyzed to yield them giving rise to aldoses and ketoses. They can be classified as monosaccharides, disaccharides, oligosaccharides, and polysaccharides.
Stereoisomerism (molecules with the same chemical formula, the same molecular structure, but different spatial arrangement) which can be geometric (*cis, trans configurations*) or optical isomerism (*D and L notations* resulting in chiral or asymmetric centre enantiomers, diastereomers, epimers) are distinguished. Carbohydrates can be metabolized via glycolysis, tricarboxylic acid cycle, electron transport chain (to yield ATP), pentose phosphate pathway (to yield NADPH), glycogenesis (for storage) etc. The mitochondrial electron transport chain takes away electrons from electron donor (NADH or $FADH_2$) and passes them to a terminal electron receiver (O_2) through a series of redox reactions. These reactions are coupled to the creation of a proton gradient in the intermembrane space. There are three proton pumps, complexes I, III and IV. The transmembrane proton gradient created by the movement of electrons is used for the synthesis of ATP with the

ATP synthase. Amino acid residues are linked together by peptide bonds to form protein. Primary, secondary, tertiary and quaternary structures of proteins are distinguished. The biologic functions of proteins are diverse ranging from enzymatic, structural, transport, defense to storage. Bovine spongiform encephalopathy (mad cow disease) and scrapie of sheep are caused by defections of certain proteins. Urea cycle starts with the formation of carbamoyl phosphate following condensation of ammonia, carbon dioxide and ATP in the presence of N-acetylglutamate which occurs in the liver mitochondria. Ornithine transcarbamoylase catalyzes the formation of citrulline which exudes the mitochondria into the cytosol. Other reactions leading to the formation of argininosuccinate, arginine and urea via catalysis by argininosuccinic acid synthase, argininosuccinase and arginase respectively occur in the cytosol of the hepatocytes. Metabolic disorders associated with urea cycle reactions include hyperammonemia types 1 &2, citrullinemia, argininosuccinic aciduria and hyperarginemia. Glucose 6 phosphate dehydrogenase deficiency causes haemolysis of red blood cells. This is because there will be a reduction in NADPH generation. NADPH is responsible for maintaining reduced glutathione which protects RBC membranes against oxidative damage. Oxidative damage to RBC leads to oxidation of haemoglobin, generation of Heinz inclusion body and increased red blood cell membrane permeability and lysis and the attendant haemolytic anaemia. Inborn errors of metabolism (IEM) include a group of disorders in which a single gene defect causes a clinically significant block in a metabolic pathway culminating in accumulation of the substrate or deficiency of the product. Haemoglobin is a protein within the erythrocytes that is involved in the transport of oxygen, carbon dioxide and buffering of hydrogen ions. Porphyrins are a group of cyclic tetrapyrrole, consisting of four pyrrole nuclei with their α (adjacent to the β) carbon atoms linked together by methane (-C) bridges. Porphyria are those disease states of porphyrins and porphyrias can be found in the bovine, swine, and cats. Bile pigments are the coloured compounds, which are broken down products of the haemoglobin. Examples of types of bilirubin are conjugated bilirubin and unconjugated bilirubin. Hemoglobinopathy

refers to the pathology or disease of haemoglobin which could result from gene mutations leading to abnormal chains of the globin. Mutations in the beta chain gene lead to productions of HbS, HbC and HbE. Sickle cell disease, thalasemias, and methemoglobinemia are various hemoglobinopathies that have been studied while glycosylated hemoglobin is an acquired hemoglobinopathy where glucose is non-enzymatically adducted to hemoglobin.

Exercises

1. Highlight all the classes of carbohydrate you know with examples.
2. Briefly discuss the components of the electron transport chain.
3. Briefly discuss the inhibitors of electron transport chain.
4. What are the energy rich compounds involved in the process of the electron transport?
5. Discuss the relationship between the electron transport chain, glycolysis, and TCA cycle.
6. Describe the primary, secondary, tertiary, and quaternary structures of proteins and highlight the forces that stabilize them.
7. What is transamination reaction and name the biological importance of these reactions?
8. Differentiate between essential and non-essential amino acids.
9. Enumerate five metabolic disorders of urea cycle.
10. Mention three hemoglobinopathies you know.
11. Highlight the consequences of Glucose-6-phosphate dehydrogenase deficiency.
12. Discuss five inborn errors of e amino acids metabolism.
13. Write an essay on the different classes of porphyrias in animals.
14. Write short notes on Bovine Congenital Erythropoietic Porphyria.
15. Write concisely on hyperbilirubinaemia and bilirubinuria.

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Chapter 8

VBC 202: Biochemistry II

(Chemistry and Biochemistry of Lipids, Nutritional Biochemistry, Fluid and Electrolyte Balance)

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Overview

This chapter on chemistry and biochemistry of lipids, nutritional biochemistry, fluid and electrolyte balance will help students navigate the complex discipline of biochemistry with a clear and coherent presentation.

Lipids are a diverse group of organic compounds that play an important role in biological systems. Triglycerides are abundant lipids in the human body and serve as a long-term energy storage form. They consist of glycerol and free fatty acid molecules. Triglycerides are stored in adipose tissue and can be broken down through a process called lipolysis to release fatty acids for energy production.

Nutritional biochemistry is the study of nutrients' interaction with the body at the molecular level and how they affect various metabolic processes. It encompasses the study of nutrients like carbohydrates, proteins and lipids and micronutrients like vitamins and minerals.

Carbohydrates are a major source of energy in the diet. They are broken down into glucose during digestion and serve as fuel for various cellular processes. The metabolism of carbohydrates involves processes such as glycolysis, gluconeogenesis, tricarboxylic acid (TCA) cycle and

glycogen synthesis and storage. Proteins are essential for growth, maintenance, and repair of body tissue. They are composed of amino acids linked together by peptide bonds.
Fluid and electrolyte balance refers to the regulation of body fluids and the maintenance of the proper concentration of electrolyte ions in the body. It is essential for normal physiological function and homeostasis. Water is the most abundant component of the body and is involved in various processes such as digestion, transportation of nutrients and temperature regulation.
Where necessary, figures have been used in this write-up, simplified with step-by-step annotations and clear captions.
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Objectives

The objectives of this course are to:

1. explain the chemistry and biochemistry of lipids, nutritional biochemistry, fluid and electrolyte balance;
2. describe major nutritional vitamins, fluid and electrolyte deficiencies;
3. relate the chemistry and biochemical roles of prostaglandins;
4. explain factors affecting nutrient requirement in animals, basal metabolic rate, specific dynamic action and energy utilization; and
5. describe metabolic diseases in animals.

Introduction

Lipids are commonly known as fat and oils and characterized by their insolubility in water and solubility in organic solvents. They serve as a concentrated source of energy, structural component of cell membranes and precursor for the synthesis of various bowel-active molecules. Lipids can be classified as saturated and unsaturated based on their chemical structure.

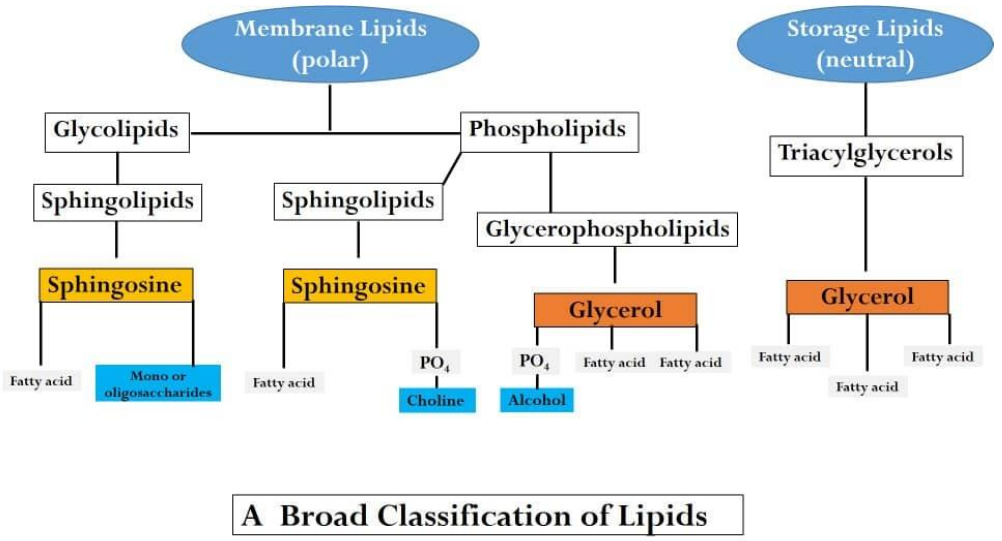


Figure 1. Classification of lipids based on their composition and storage form.

Biological Roles of lipids

1. Excellent energy reserves
2. Structure of cell membranes
3. Organ padding
4. Body thermal insulation
5. Essential fatty acids (EFA)
6. Hormone synthesis
7. Fat-soluble vitamin absorption

Characteristics of Lipids

Naturally occurring unsaturated vegetable oils have almost all Cis bonds. The conversion of Cis bond to Trans bond occurs during frying. Fatty acids with trans bonds are known to be carcinogenic. Lipids can either be saturated (e.g., animal oil like meat, milk, butter, vegetable oil and palm kernel oil) or unsaturated with one (monounsaturated) e.g., olive oil, canola oil, avocado or more double bonds

(polyunsaturated) e.g., safflower, corn, cottonseed, sunflower oil and soybean oil, etc.

Lipids Disorders: Lipids deficiency (Inadequate lipids intake)
Lipids excess (Excessive lipid intake)

Lipid Metabolism

Metabolism is the term that describes the sequences and succession of chemical processes taking place in living organisms. The chemical processes involve utilization of nutrients along with excretion of metabolic end products from the body.

The metabolic processes are of two types:

a. Catabolism: which is degradation of complex molecules into simpler products.
b. Anabolism: which is synthesis of complex molecules from simpler substances.

As a result of various metabolic processes, energy is made available for synthesis of macromolecules.

Lipids are acted upon by lipase to produce fatty acids and glycerol which is glycogenic.

Glycerol Metabolism

Glycerol enters the glycolytic pathway to produce glycerol-3-phosphate and dihydroxylacetone phosphate. Glucose can be produced from dihydroxylacetone phosphate by gluconeogenesis which can then be metabolized to generate energy. In the same way, dihydroxylacetone phosphate can enter the glycolytic pathway to produce pyruvic acid and then enter the tricarboxylic acid cycle to produce carbon dioxide, water and energy.

Fatty Acid Metabolism

A major part of the energy derived from fats is provided by fatty acids. The sources of fatty acids are:

(a) Dietary sources: Fatty acids formed from the digestion of dietary lipids are carried to the liver. From the liver, they are transported to cells in a bound form with albumin.
(b) Endogenous sources: free fatty acids formed from body triglycerides are used for energy production. Although the plasma free fatty acids (FFA) level is lower than blood glucose level, they are rapidly utilized by peripheral tissues. The FFA has a half-life of 3-4 minutes.
Fatty acids metabolism could be through any of the following means:

Alpha (α)-oxidation: This is a process in which fatty acids are degraded by sequential removal of one carbon from the carboxyl end after the oxidation of α-carbon to α-keto form. It occurs in peroxisomes and mitochondria and in plants. Unlike β-oxidation, it does not generate energy and requires no CoA intermediates. Phytanic acid is the only fatty acid oxidized by α-oxidation. It is derived from plant alcohol phytol, which is present in dairy products. It cannot undergo β-oxidation due to a methyl group at the β-carbon. α-oxidation converts phytanic acid to pristanic acid, which undergoes β-oxidation to produce small molecules.
Beta (β)-oxidation: It is a process in which fatty acids or acyl-CoAs are degraded by sequential removal of two carbon fragments from the carboxyl terminus after oxidation of the β-carbon of fatty acids to the β-keto form.
Omega (ω)-oxidation: It is a process in which the ω-carbon of fatty acids is oxidized to a carboxylic group. Thus, this oxidation converts fatty acids to dicarboxylic acids and occurs in the smooth endoplasmic reticulum. Beta-oxidation can occur from both ends. Medium chain fatty acids of adipose tissue undergo ω-oxidation during ketosis.

Regulation of Beta-oxidation

Beta-oxidation is the most common means of fatty acid oxidation. It is regulated at the control point which is under the control of carnithine acyl transferase I (CAT-I). In the fed state, the concentration of malonylCoA is increased and blocks the activity of CAT-I. However,

when there is starvation, malonylCoA concentration is decreased and this releases CAT-I to activate fatty acid oxidation.

Biosynthesis of Fatty Acids

In avian and mammalian species, fatty acids are synthesized in the cytoplasm (in liver, adipose tissue, mammary glands, heart, lungs and brain) from acetyl CoA, a substrate that may be derived from carbohydrates, amino acids and fatty acids. Fatty acid synthase, a multi-enzyme complex, is responsible for the formation of fatty acids using acetylCoA derived from pyruvate as the substrate and palmitate is the end product. AcetylCoA carboxylase activity regulates fatty acid biosynthesis. It is under allosteric and hormonal control (Wakil and Stoops, 1983).

Biosynthesis of Compound Lipids

The major compound lipids present in mammalian membranes are phospholipids and glycolipids. Phosphatidyl choline or lecithin, phosphatidyl ethanolamine or cephalin and sphingomyelins are major components of the cell membrane. Cardiolipin is another phospholipid found in the mitochondrial membrane while phosphatidyl inositol is important in signal transduction. Biosynthesis of lecithin and cephalin occurs in the liver and adipose tissue. The precursor is phosphatidic acid which is the major route for the synthesis of these lipids. Nitrogenous bases are activated in the cytosol prior to their incorporation into phospholipids.

Lipoproteins

Lipoproteins are lipid protein complexes found in plasma and held together by non-covalent forces. The protein part of lipoprotein is called apolipoprotein or apoprotein.

Functions of Lipoproteins: Lipoproteins are involved in the transportation of lipids in the body.

1. Chylomicrons: They transport dietary or exogenous triglycerides from the intestine to the liver.
2. Very low-density lipoproteins (VLDL): They are involved in the transport of endogenous triglycerides from the liver to extra hepatic tissues.
3. Low density lipoproteins (LDL): LDL is the major vehicle for the transport of cholesterol from the liver to extra hepatic tissues.
4. High density lipoproteins (HDL): HDL is the major vehicle for the transport of cholesterol from extra hepatic tissues to the liver.

Fatty Liver

Liver contains about 5% lipids of which a quarter is triglycerides. Extensive accumulation of lipids between 25-30% in the liver is known as fatty liver. Triglycerides and fatty acids may occupy the entire cytoplasm of hepatocytes. Factors responsible for the accumulation of lipids in the liver include:

(1) Raised plasma free fatty acid level.
(2) Metabolic block in the production of lipoproteins.
(3) Toxic substances.

When accumulation of lipids in the liver becomes chronic, fibrotic changes take place in hepatocytes, which progresses to cirrhosis and finally impaired liver function.

Lipid Peroxidation

The action of atmospheric oxygen on fats results in the formation of peroxides. It occurs *in vivo* too. Lipid peroxidation is a chain reaction, and it is initiated by free radicals. Free radicals are molecules with unpaired electrons in the outer orbitals. They are reactive and contain oxygen, hence they are called reactive oxygen species (ROS). In biological systems, free radicals are generated by oxygen radicals and superoxide. Malondialdehyde (MDA) and other small molecules are the products of lipid peroxidation, hence MDA estimation is used to assess the extent of lipid peroxidation.

Superoxide (0_2) cannot initiate lipid peroxidation, but it generates ROS or free radicals like singlet oxygen (O^-) and hydroxyl radical (OH^-). These may initiate lipid peroxidation. Light or heavy metals may generate free radicals which can initiate lipid peroxidation. Membrane lipids, particularly polyunsaturated fatty acids, are in contact with oxygen- and metal-rich environments. So, they are susceptible to lipid peroxidation causing membrane dysfunction. Lipid peroxidation is associated with ageing, diabetes, cancer, necrosis, inflammatory or autoimmune disorder, and cardiovascular dysfunction like atherosclerosis.

Free Radicals Scavenger Systems

Free radicals initiate lipid peroxidation; hence, the body devises a means of removing free radicals (Halliwell and Gutteridge, 2003).

(a) *Enzymatic free radical scavenger system*: antioxidant enzymes like superoxide dismutase, gluthathione-S-transferase, catalase, peroxidase and gluthathione peroxidase.

(b) *Non-enzymatic free radical scavenger system*: such as glutathione, melatonin, tocopherol, ascorbic acid, lipoic acid, uric acid, carotenes, caffeine and bilirubin. They have antioxidant properties.

Some toxins work by generating free radicals e.g., carbon tetrachloride, alloxan and hydroxyl dopamine. Mostly, they create oxidative stress, which results in impaired function of tissues (Ola-Davies *et al*., 2013).

Cholesterol Metabolism

Cholesterol is the waxy, fat-like substance found in the body. It is an important part of the cell membrane and helps in the production of certain hormones**.**

Cholesterol synthesis takes place in all nucleated cells particularly in the liver, adrenal cortex, testes, ovaries, brain, placenta, aorta, and skin. The enzymes of cholesterol biosynthesis are present in microsomes and cytosol of the cells.

AcetylCoA generated from breakdown of carbohydrates, fats and amino acids acts as a precursor of cholesterol, while the hexose monophosphate shunt generates NADPH required for cholesterol synthesis.
Cholesterol synthesis occurs through the following process:
3 AcetylCoA (C_2) →Mevalonate (C_6) →Isoprenoid (C_5) →Squalene (C_{30}) →Lanosterol (C_{30}) →→→Cholesterol(C_{27}).

The regulation of cholesterol biosynthesis is at the level of HMG-CoA reductase activity which is under the hormonal and feedback mechanism in the liver.

Catabolism of cholesterol: Cholesterol is not degraded into small compounds because enzymes to breakdown steroid nucleus are lacking. However, it is converted to bile acids in the liver and eliminated through the bile. Cholic and chenodeoxy cholic are the end products of cholesterol catabolism which are called primary bile acids. In the intestine, a part of bile acids undergoes deconjugation and dehydroxylation by intestinal bacteria to form deoxycholic acid and lithocholic acid which are called secondary bile acids.
Bile salts are formed when primary bile acids are activated to their corresponding CoA. They are then conjugated with glycine and taurine to form taurocholate, glycocholate, taurochenodeoxy cholate and glycochenodeoxy cholate. They then combine with sodium and potassium ions to form bile salts.
Other catabolic fates of cholesterol relate to steroid hormones. These are the five classes of steroid hormones formed from cholesterol: progesterone, testosterone, cortisol, aldosterone and estradiol. The corpus luteum and placenta synthesize progesterone, the testes and ovaries produce testosterone and estradiol, respectively while the adrenal cortex produces aldosterone and cortisol. NADPH is needed for steroid hormone formation. The synthesis occurs in the mitochondria and smooth endoplasmic reticulum. Pregnenolone is the common intermediate of all the classes of steroid hormones biosynthetic pathway

while the enzymes dehydrogenases, hydroxylases and lyases are involved.

Biochemistry of Prostaglandins

Prostaglandins (PG) are twenty-carbon lipid-based compounds containing a five-carbon ring (Cyclopentane). In nature, they are formed from poly-unsaturated twenty-carbon fatty acids (eicosanoids). Prostaglandins play important physiological roles in reproduction. They are also important in inflammation (pro-inflammatory substance).

Chemistry of prostaglandins

The basic chemical structure or skeleton of prostaglandins is prostanoic acid. It contains a five-carbon ring, cyclopentane. Sometimes, they are referred to as prostanoids. Prostaglandins are classified according to the functional group, the number of double bonds and the fatty acid from which they are derived. They are designated as A, B, C, D, E, F, and I according to the functional groups. There are three classes based on the number of double bonds and the fatty acid precursors (for example PGF_1, PGF_2 and PGF_3). The subscript 1, 2 and 3 refer to one, two and three double bonds, respectively. Thromboxanes (TXA) and leukotrienes are also of eicosanoid origin. They have the basic prostanoic acid structure.

Metabolism of Prostaglandins

Prostaglandins are synthesized from various tissues to serve many functions. The precursors are eicosanoic acids. Biosynthesis of PG from eicosatrienoic (linolenic acid), eicosatetraenoic (arachidonic acid), or eicosapentaenoic acid is straightforward, involving the formation of only one new C-C bond. It starts with the removal of hydrogen atom at c-13 and addition of oxygen at c-15. The enzyme involved is called prostaglandin synthetase or cyclooxygenase (cox). The carbons in prostaglandins are numbered one to twenty starting at the carboxyl carbon and following the numbering system of the precursor fatty acids. Most prostaglandins (except for PGI) are rapidly metabolized in the lungs by the enzymes called 15-hydroxyprostaglandin dehydrogenase

(15-OH-PGDH) and PG reductase. The product is excreted in the urine. The table below presents the functions of PG in various tissues.

Table 1: Type, tissue location and functions of prostaglandins

Prostaglandins	**Organ /Tissue**	**Function**
PGF_2, PGE, PGI	Uterus	Contraction
PGF_2, PGE	Cervix, brain	Dilation, Stimulation of GnRH, LHRH
PGE, PGI, TXA_2	Lungs	Dilation, constriction
PGF	Copus luteum	Luteolysis
PGI, TXA_2	Arteries	Antithrombotic effect

Foot note; GnRH- Gonadotropin releasing hormone, LHRH- Leutinising hormone releasing hormone

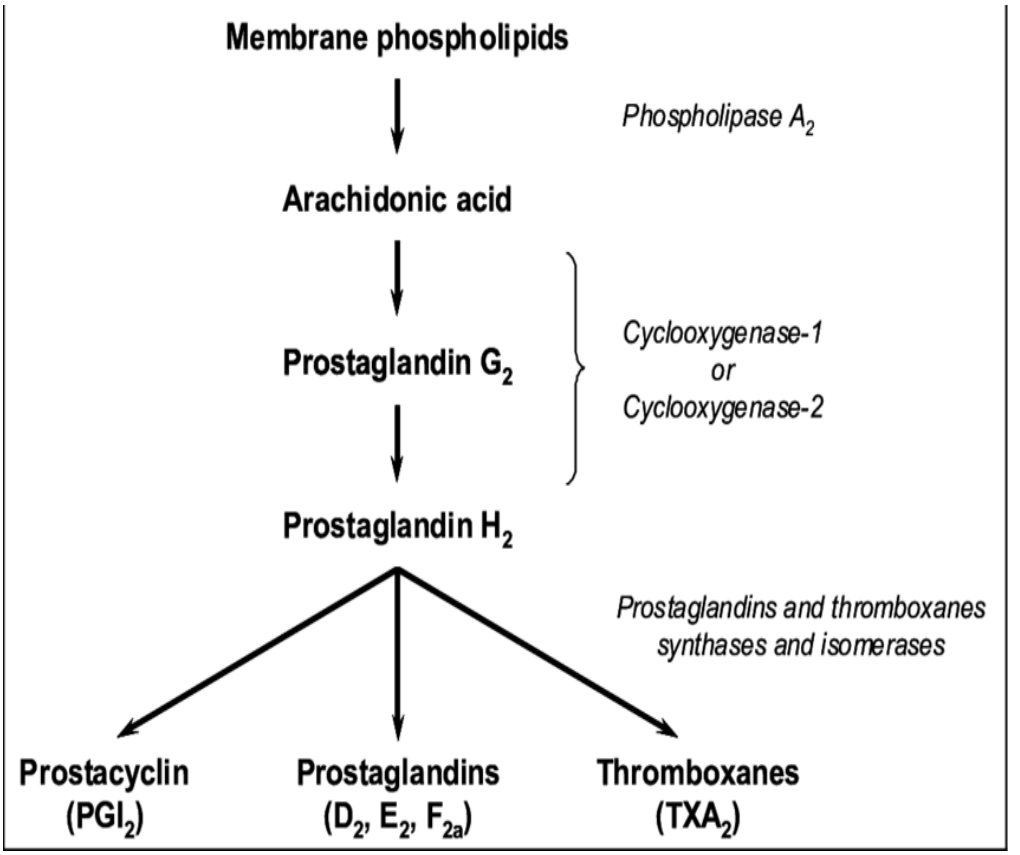


Figure 2. Pathway for prostaglandins synthesis.

Nutritional Biochemistry

The utmost challenge associated with successful livestock management and production is nutrition. Understanding animals' nutritional demand, utilization and nutritional values of food is the key to successful management and production in farms. Food is a general term for edible materials, while nutrient is the component of food that is digested, absorbed and metabolized in the body. Animal nutrition deals with the sources, preparation, processing, and evaluation of animal feed as well as their feeding. Nutritional biochemistry is the science that deals with analysis, requirement, and utilization of nutrients in health and disease.

Generally, food has water and dry matter (DM) components. The DM includes organic (carbohydrate, protein, lipid) and inorganic (minerals) components.

General nutritional requirements

When animals take in food, the nutrients in the food are used for maintaining body functions (respiration, blood flow, nervous system functions, etc.), growth and products (milk, wool). These body functions require specific types and amounts of nutrients. The requirements are influenced by several factors. There are six classes of nutrients required by the body. These are: carbohydrates, proteins, lipids, water, vitamins and minerals. Sometimes, energy is included as nutrient to represent lipid and carbohydrate.

Factors affecting nutrients requirement

The requirements and the extent of nutrient utilization in animals is influenced by the following factors: species, breed, age, sex, weight, body condition, physiological state, genotype, environment, work/exercise, disease, and stress. The nutrient requirements have four key components: Maintenance, Lactation, Growth, and Reproduction.

Maintenance: The maintenance component consists of all the nutrients required for the animal to perform basic physiological functions e.g., breathing. Large animals require more nutrients for maintenance, especially energy and protein. Pregnancy and lactation cause increased requirement for maintenance. The more the activity, the more energy requirement for maintenance. Similarly, rough environment will increase maintenance energy needs.

Lactation: Heavy lactation requires a higher nutrient supply. In dairy animals, nutrient requirement is directly proportional to the quantity and quality of the milk.

Growth: The nutrient requirement for growth is based on weight added and component gained (more muscle or more fat). For example, the protein requirement will be greater for young animals because they are

gaining more muscle than fat. Also, the nutrients required by young animals per unit body weight are greater.

Reproduction: Changes to requirements for reproduction are estimated using expected birth weight and stage of gestation. The requirements are for maternal and foetal tissue development. Foetal tissues have priority for nutrients over maternal tissues. Usually, more nutrients are needed to support rapid foetal growth in the third trimester of pregnancy. When nutrients are deficient prior to breeding, fertility can be low and maintaining pregnancy will be difficult. Undernourishment during growth can cause delayed sexual maturity.

Energy aspect of diet

Energy is released during metabolism. It is needed for growth, production and other vital processes and it is mostly extracted from carbohydrate and lipid or fat content of feedstuff. Energy in feed is classified into four groups: Gross energy, digestible energy, metabolizable energy, and net energy which is the energy available for maintenance and production. In the process of releasing these energy groups, losses occur in urine, faeces, methane production in rumen and heat production.

Basal metabolic rate (BMR)

The total amount of energy used by an animal over a period of time is called its metabolic rate. The word "basal" in basal metabolic rate (BMR) refers to the absence of physiological and pathological conditions like exercise, stress, disease, etc. BMR is therefore the amount of energy used by the animal at a time interval when the animal is completely at rest. BMR is measured while the animal is within its thermoneutral zone, resting, fasting (i.e., postabsorptive), and not reproducing or growing, and it is measured during the inactive part of the animal's daily cycle. BMR is affected by body mass, sex and age (Pethusamy *et al*., 2009).

Specific dynamic action (SDA)

It is defined as the extra heat production over and above the BMR or caloric value of a given amount of food when used by the body. Proteins

account for about 30%, carbohydrates 6% and fats 4% of the SDA. For example, when protein, carbohydrate or lipid containing 100 kcal is metabolized in the body, the heat produced is not 100 kcal but 130, 106 and 104 kcal, respectively. The extra heat comes from the combustion of the tissue substances causing loss of body weight. To prevent this loss of weight, the subject must be supplemented with extra calorific allowance for the SDA of the food itself.

Biochemical importance: SDA is used for metabolism, digestion, and absorption. It is important in anabolism and catabolism of biomolecules like glycogen, cholesterol, triacylglycerol, etc. It also provides the activation energy required for biochemical reaction which is supplied initially.

The SDA of carbohydrate is to represent the energy liberated in excess of that required for the conversion of glucose to glycogen. After a fast, when glycogen store is depleted, ingested glucose (which is mostly converted into glycogen) exhibits pronounced SDA.

There is evidence that the process of lipogenesis from glucose produces more SDA than during its oxidation to CO_2 and H_2O

The SDA of protein is largely due to oxidative deamination and formation of urea and is an important factor in the regulation of body temperature. With fats and carbohydrates, the extra heat is used in the performance of work. The thyroid gland regulates the SDA of fats and carbohydrates.

Bovine ketosis

This is a common metabolic disorder of cattle. It represents high concentration of ketone bodies, β-hydroxybutyric acid (βHBA), acetoacetic acid (ACAC), and acetone, in all body fluids, due to high glucose demand and massive lipid/fat mobilization. It occurs during lactation and rarely in late gestation which resembles pregnancy toxaemia of sheep. High glucose demand is required for lactogenesis or milk synthesis. Gluconeogenesis is increased due to low supply and high demand. Fat mobilization for gluconeogenesis requires a high concentration of fatty acids in the liver. This produces high

concentration of ketone bodies as by-product of fat degradation. Lipid mobilized from adipose tissues releases fatty acids which enter gluconeogenic pathway. Fatty acid is converted to acetyl coA, which forms β-hydroxybutyric acid (βHBA), acetoacetic acid (ACAC), and acetone. This leads to elevation of the level of ketone bodies in blood (hyperketonaemia) and other body fluids.

Pregnancy toxaemia: pregnancy toxaemia is a common metabolic disorder of undernourished ewes due to increased foetal energy requirements in late pregnancy. This pathology is characterised by hypoglycaemia and hyperketonaemia resulting in the inability of the animal to maintain an adequate energy balance. It can occur in ewes carrying a singleton, due to nutritional deficiencies or excessive weight loss regimen. Rapid triacylglycerides (TAG) mobilization from adipose tissue occurs. This is reflected in the rapid rise of non-esterified fatty acids (NEFA) concentration in blood. The fatty acids are then degraded to ketone bodies like in bovine ketosis. In both bovine ketosis and pregnancy toxaemia, hypoglycaemia, hyperketonaemia, and impaired liver function test results are good biomarkers.

Hypocalcaemia

Hypocalcaemia results whenever there is a net efflux of calcium from the extracellular fluid in greater quantities than the intestines or bones can replace. Increased calcium demand coupled with decreased intake is the major cause. The condition can occur in an acute form precipitated by late pregnancy and early lactation, or by fasting before or during transit. Physical stress is certainly related. Hypomagnesemia may be a precipitating factor in cattle and a contributing factor in sheep. Without calcium, muscle contraction becomes abnormal and the nervous system more excitable. Seizures (called hypocalcaemic tetany or transit tetany) can result. The condition is called milk fever in cattle. It usually occurs during intense milking in dairy cows and dogs nursing multiple puppies and is due to increased calcium needs for milk synthesis.

Water soluble vitamins

Vitamins are generally regarded as organic compounds required in the diet in small amounts to perform specific biological functions for normal maintenance of optimal growth and health of an organism. Based on their solubility, they have been classified as water soluble and fat-soluble vitamins. The water-soluble vitamin group comprises eight vitamins together identified as the B-complex vitamins plus vitamin C (ascorbic acid).

The B-complex vitamins: The B-complex vitamins are vitamin B1 (thiamin), vitamin B2 (riboflavin), vitamin B6 (pyridoxine), vitamin B12 (cyanocobalamin), niacin (nicotinic acid, niacinamide), pantothenic acid, folic acid (folacin) and biotin. These vitamins are chemically diverse compounds that co-occur in the same food. They are biosynthesized by the microflora of the intestine (in small quantities) and rumen and are vital for many biochemical reactions in the body. They are generally found in living tissues (Rafeeq *et al.*, 2020).

Table 2: Selected important Coenzymes in B Vitamins

B Vitamine	**Coenyzmes**	**Groups Transferred**
Thiamine	Thiamine pyrophosphate (TPP)	Aldehydes
Riboflavin	Flavin mononucleotide (FMN) Flavin adenine dinucleotide (FAD)	Hydrogen atoms
Niacin	Nicotinamide adenine dinucleotide (NAD^+) Nicotinamide adenine dinucleotide phosphate ($NADP^+$)	Hydride ion (H-)
Vitamin B6	Pyridoxal-5-phosphate (PLP)	Amino groups

Folate	Tetrahydrofolate (FH_4)	One-carbon groups other than CO_2
Vitamin B12	5'-deoxyadenosylcabalmine	Alkyl groups, hydrogen atoms
Pantothenic acid	Coenzyme A (CoA) Acyl carrier protein (ACP)	Acyl groups
Biotin	Biocytin	Carbon dioxide

Thiamine: is mostly found phosphorylated in animal products and in non-phosphorylated forms in plants. It is derived from pyrimidine and thiazole. It is a component of a coenzyme involved in carbohydrate metabolism and supports normal nerve function. This vitamin functions as the coenzyme, thiamine pyrophosphate (TPP). It is the prosthetic group for a number of enzymes involved in decarboxylation of alpha-keto acid and transketolation reactions, such as:

a) Pyruvate dehydrogenase complex involved in the decarboxylation of pyruvate.
b) α-ketoglutarate dehydrogenase complex of the TCA cycle.
c) Transketolation in Pentose Phosphate pathway.

Deficiency syndrome is Beriberi.

Riboflavin: Functions as the coenzymes, Flavin mononucleotide (FMN) and Flavin adenine dinucleotide (FAD) involved in reactions of:

a) Fumarate dehydrogenase in the TCA cycle.
b) Succinate dehydrogenase in the TCA cycle.
c) Dihydrolipoyl dehydrogenase in decarboxylation of pyruvate.

It is part of the coenzymes required for energy production, vitamin, mineral, and drug metabolism. It has an antioxidant effect.
Deficiency syndrome is Cheilosis characterized by fissure at the angle of the mouth.

Niacin is a generic term for both nicotinic acid and nicotinamide (niacinamide) in foods. Both forms have the same vitamin activity. Niacin functions as coenzymes, Nicotinamide adenine dinucleotide (NAD) and Nicotinamide adenine dinucleotide phosphate (NADP), which

act as electron acceptors in redox reactions. It is a coenzyme to dehydrogenases catalysing over 50 different reactions and acting as hydrogen and electron carriers example:
a) Isocitrate dehydrogenase in TCA cycle.
b) Succinate dehydrogenase in TCA cycle.
c) Malate dehydrogenase in TCA cycle.
It is involved in reactions of fatty acid and steroid biosynthesis.
Deficiency syndrome is Pellagra characterized by dermatitis, dementia and diarrhoea.

Pantothenic acid 'Pantothenic' means derived from everywhere. It is a component of Coenzyme A and has wide spread occurrence in foods. It is part of the coenzyme A molecule involved in metabolism of amino acids and other nitrogenous compounds. It functions in regulation of blood glucose levels as well as synthesis of haemoglobin and neurotransmitters.
Pantothenic acid functions as the coenzymes, CoA and Acyl Carrier Protein (ACP), in metabolic reactions like:
a) Dihydrolypoil transacetylase, a component of pyruvate dehydrogenase complex
b) Enzymes of β-oxidation pathway of fat synthesis
c) Synthesis of cholesterol-HMG CoA synthase
Coenzyme A and ACP are carriers of acyl groups in many acylation reactions in lipid, amino acid and carbohydrate metabolism. Example is pyruvate to acetyl CoA.
Deficiency leads to cardiovascular instability and neuromotor disorder.

Folic acid (pteroylglutamic acid) is found in nature but can be produced commercially. Folates and folacin are the derivatives of folic acid occurring naturally. They contain one or more linked molecules of glutamic acid. Folic acid is formed by conjugating glutamic acid to pteroic acid inside the cell. It is reduced to tetrahydrofolate to serve as coenzyme in DNA synthesis and metabolism of amino acids and is required for cell division and maturation of red blood cells.

Folic acid functions as coenzyme, tetrahydrofolic acid (FH_4) derivative or coenzyme F. Folates carry out their metabolic functions as carriers of one carbon unit in the tetrahydrofolic acid (FH_4) which is the coenzyme form. These are carbon units generated during amino acid metabolism which are used in interconversion of amino acids and in the biosynthesis of purines and pyrimidines which are components of nucleic acids. Example of reactions involving the folate coenzyme, one carbon unit normally accepted by FH_4, include:
Formyl (CHO), Methyl (CH_3), Formiamino ($CH=NH_2$), Methenyl (CH), and Methylene (CH_2).
Deficiency syndrome is macrocytic anaemia.

Pyridoxine (Vit B6) is synthesized from deoxyxylulose 5-phosphate and L-threonine or from glyceraldehyde-3-phosphate and d-ribulose 5-phosphate. It exists in many forms such as pyridoxine, pyridoxal, and pyridoxamine. These are converted to pyridoxal phosphate (PLP) and pyridoxamine phosphate (PMP), which are coenzymes in metabolism of amino acids and glycogen. It is essential for new cell synthesis, normal blood formation and neurological function.
Pyridoxine functions as coenzyme, pyridoxal phosphate (PLP) is involved in many non-oxidative transformations of amino acids and other molecules such as:
a) Decarboxylation reactions e.g., decarboxylation of histidine to histamine by histidine decarboxylase.
b) Deamination reaction
c) Racemization reaction
d) Transamination reaction by transaminases

Deficiency syndrome is characterized by seborrhoeic dermatitis about the eye, nose, mouth and behind the ear.

Cyanocobalamin (Vit B_{12}).
The most important compound with vitamin B_{12} activity is **cyanocobalamin**. The central ring structure of the molecule is a

'corrin' ring with a central cobalt atom. It occurs only in animal tissues and as a metabolite of certain microorganisms. It can be found bound to peptides in its natural form and is essential for metabolism of carbohydrates, proteins, and fats. It is involved in elongation of fatty acids as a coenzyme.
Vit B_{12} functions as coenzyme and the active form of the coenzyme is:
a) Methylcobalamin
b) 5" Deoxyadenosyl cobalamin

Enzymes requiring Vit B_{12} majorly catalyse 2 groups of reactions:
i) Intramolecular rearrangement
ii) Methyl group transfer.
Plants do not manufacture or require Vit B_{12}. It is found exclusively in foods of animal origin as it is synthesized only in microorganisms especially in ruminants' gut microflora.

Deficiency syndrome is pernicious anaemia caused by absorption failure.

Biotin (Vit H)
The coenzyme form of biotin is biocytin. Biotin functions in carboxylation and decarboxylation reactions involving transfer of one carbon fragment. Therefore, biotin is a carrier of active carbon dioxide catalysed by carboxylases such as:
a) Acetyl CoA carboxylase
b) Alpha-keto carboxylase
c) Amino carboxylase
d) Decarboxylases

The chemical structure of **biotin** is such that eight different isomers are possible and, of these, only the dextro-rotatory or d-biotin possesses vitamin activity. It takes part in metabolism of carbohydrates, fats and amino acids as a coenzyme.

Vitamin C (ascorbic acid)

The active form of Vitamin C is L-ascorbic acid. Vitamin C serves as a reducing agent to a number of hydroxylation reactions. For example, it reduces iron from ferric to ferrous state. Although several compounds possess vitamin C activity, the most important is L-ascorbic acid which is like monosaccharide and is present at high levels in some fruits and vegetables and is also found in animal organs such as liver and kidney. Ascorbic acid is the enol form of 3-keto-1-gulofuranolactone. The enediol groups at C-2 and C-3 are sensitive to oxidation and can easily convert into a di-keto group by losing two hydrogens. Some vitamin C is converted to dehydro ascorbic acid after oxidation. Sodium-dependent vitamin C transporter (SVCT) transports vitamin C while the oxidized form (dehydro ascorbic acid) is transported by glucose transporter-2 (GLUT 2).

Vitamin C is effective in improving the immune system, capillary blood vessels and protecting dental health. It can use iron, calcium, thiamine, riboflavin, folic acid, pantothenic acid with vitamins A and E in the body more conveniently. It is effective in the absorption of non-heme iron and transportation of deposited iron to the bone marrow by reducing it. Ascorbic acid is a coenzyme for many enzymes. Thus, it plays a role in collagen synthesis, steroid hormone metabolism and synthesis of some neurotransmitters. It is also an electron donor, a reducing agent and antioxidant (Bulama *et al.*, 2020). Antioxidants neutralize free radicals and prevent tissue damage by giving one or two electrons. Scurvy is a condition that develops when vitamin C is deficient. Some studies have shown that vitamin C deficiency has a positive correlation with obesity.

Scurvy

Humans and some animal species (guinea pigs, bats, some birds, primates) lack the hepatic enzyme 1-gulonolactone oxidase, which is essential for the conversion of L-gulonolactone to L-ascorbate. The absence of ascorbic acid reduces the function of prolyl hydroxylase which is required to form hydroxyproline. Hydroxyproline stabilizes the collagen triple-helix. Collagen lacking hydroxyproline is more fragile and contributes to clinical manifestation of scurvy including blood clotting

defects. Those species require ascorbate in their diet to synthesize collagen and intracellular ground substance as well as for the catabolism of cholesterol into bile acids.

Obesity

A disorder of body weight regulatory systems causes build-up of excess body fat (>20% of normal body weight). Fat cells are called adipocytes, so called because fat/triglycerides are deposited there. Deposition can increase the cell size to a limit. Prolonged over nutrition stimulates pre-adipocytes (precursor cells that are capable of becoming mature fat cells) in adipose tissue. The stimulated pre-adipocytes can proliferate and mature into adipocytes which increases their number. Thus, obesity is due to hyperplasia and hypertrophy of adipocytes. Energy imbalance over a long period of time results in obesity. This is due to increased calories consumption and decreased utilization. Many factors such as behavioural, social interactions, environmental and genetics are important in the pathogenesis of obesity.

Piglet anaemia

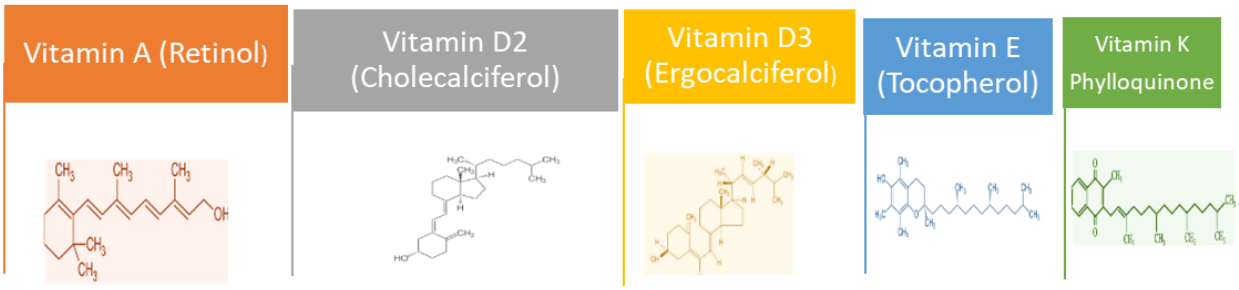
Piglets are naturally iron-deficient chiefly due to their low iron reserves at birth. The low iron reserve is because of poor trans-placental transfer to the foetus. Their rapid growth together with the low iron levels in sow milk is another contributing factor. Hence, piglets regularly become iron-deficient within days of birth which quickly develops into anaemia in the absence of iron supplementation (Abbas *et al.*, 2022). Iron is required for red blood cells production which drops when iron is deficient. Most of the functionally active iron (60%) resides in the form of haemoglobin and most of the remainder is required for adequate enzymic function and the generation of myoglobin. Liver iron stores and sow milk together cannot meet such high iron requirement of piglets. Piglets are born with iron reserve of 35–50 mg which is only sufficient for 3–4 days since daily iron requirements range from 7 to 16 mg.

Fat-Soluble Vitamins

The fat-soluble vitamins are A, D, E, and K (ADEK). These vitamins are soluble in organic solvents and are absorbed in the lymphatic system. They are broken down by bile and any disease that causes impairment of fat absorption may cause a deficiency of fat-soluble vitamins in the body. A deficiency of these vitamins is usually accompanied by classical symptoms in animals.

Notably, fat-soluble vitamins are stored for a long time in the liver, skeletal muscles, and adipose tissue. Therefore, clinicians should note that an overdose of these vitamins may result in toxicity.

Table 3: Fat-soluble vitamins: structure, function, deficiency and dietary



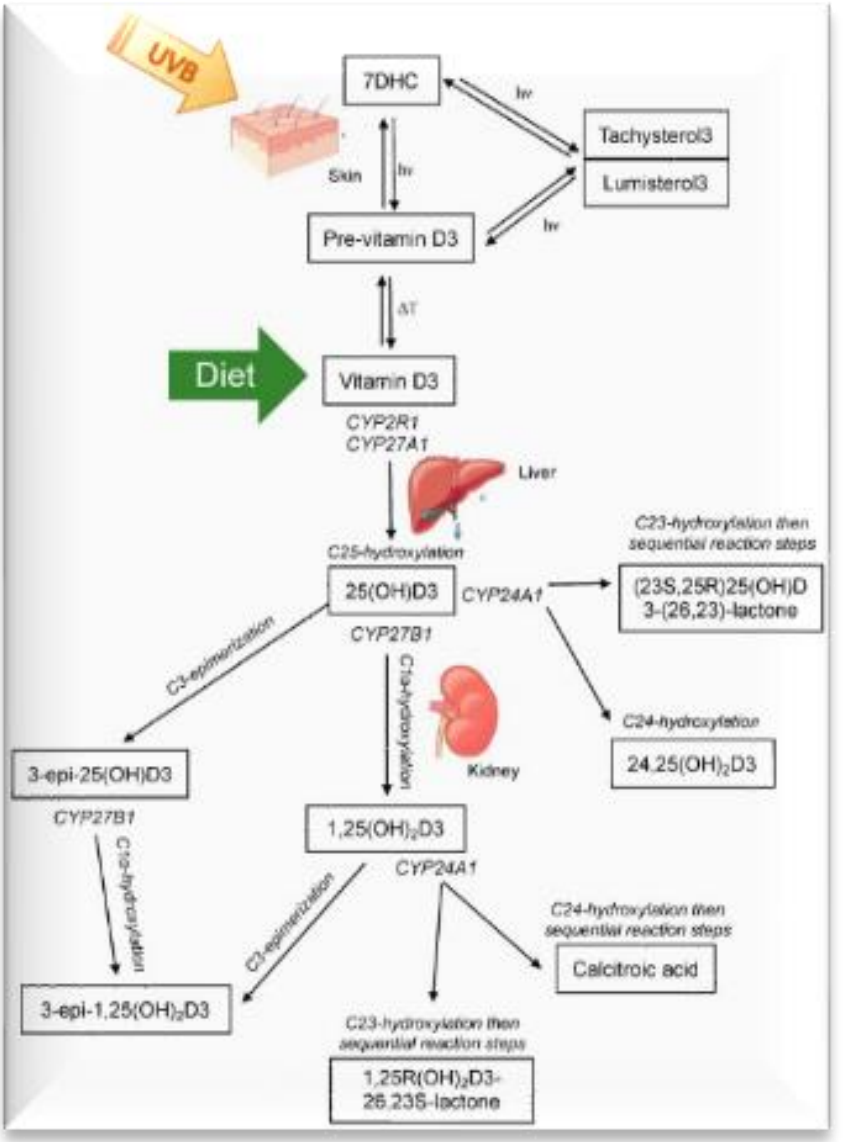
sources.

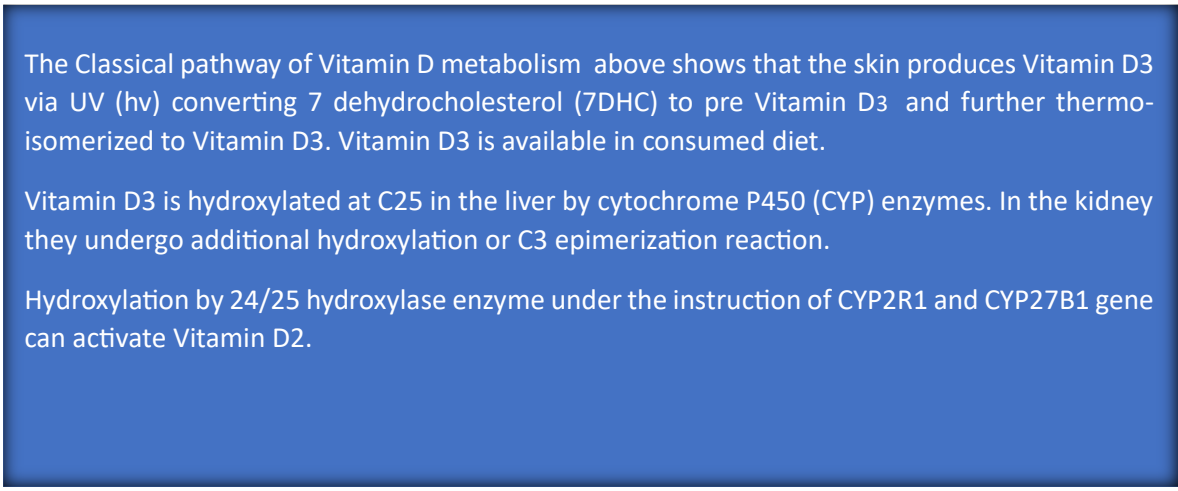
Vitamins	Function	Deficiency	Dietary Source
Vit A.	Immune function, Improved vision, Growth of cells.	Night blindness, Yellowing of the skin.	Liver, milk, fish oil, eggs mangoes, tomatoes, red bell pepper. Yellow and green plants.
Vit. D	Regulation of calcium absorption, maintenance of	In piglets: lameness, weakness, muscle fasciculation,	Dairy, egg, fish oil, cod oil, offal, meat; Fungi (ergocalciferol).

	phosphorus level.	tetany, tremor, and death.	
Vit E	Antioxidant	Mild hemolytic anemia	Vegetables, nuts, fruit, seed oils, and seed.
Vit K	Involved in blood clotting and protein synthesis.	Bleeding Diathesis	Egg yolks, green leafy vegetables.

Vitamin D metabolism

The classical pathway of Vitamin D metabolism is shown in the Figure 3 below.


UVB
7DHC
hv
Tachysterol3
Lumisterol3
Skin
hv
Pre-vitamin D3
hv
ΔT
Diet
Vitamin D3
CYP2R1
CYP27A1
Liver
C25-hydroxylation
25(OH)D3
CYP24A1
C23-hydroxylation then sequential reaction steps
(23S,25R)25(OH)D 3-(26,23)-lactone
CYP27B1
C3-epimerization
C1α-hydroxylation
Kidney
C24-hydroxylation
24,25(OH)2D3
3-epi-25(OH)D3
CYP27B1
C1α-hydroxylation
1,25(OH)2D3
CYP24A1
C3-epimerization
C24-hydroxylation then sequential reaction steps
Calcitroic acid
3-epi-1,25(OH)2D3
C23-hydroxylation then sequential reaction steps
1,25R(OH)2D3-26,23S-lactone



Source: Hurst *et al*., 2020.

Figure 3: Classical pathway of Vit. D metabolism

Vitamin E

Vitamin E is made of four tocopherols and tocotrienols linked to eight fat-soluble compounds.
Sources: Vegetables, nuts, fruit, seed oils, and seed.
Biochemical activities: It is an antioxidant that protects the cell membrane from reactive oxygen species. It can perform multiple functions as a supplement.
Deficiency: It may cause ataxia, myopathy, peripheral neuropathy, and other nerve disorders.

Vitamin K

Sources: Green vegetables, liver, fish, beef cereals, and eggs. It may also be produced by bacteria in the gut.
Metabolism: It exists as K1 (plant form) and K2 (bacterial form). It serves as a co-factor in activating Vitamin K-dependent proteins. Vitamin K metabolism occurs mainly in the liver. Coumarin and warfarin act as anticoagulants by blocking vitamin K epoxide reductase formation in the liver.

Deficiency: results in liver and intestinal diseases, cystic fibrosis, hypoprothrombinemia and coagulopathy.

Calcium and Phosphorous Metabolism and significance

In addition to being necessary for skeletal mineralization, calcium and phosphate are essential for animal physiology (such as neuromuscular function). In order to understand problems of the levels of calcium and phosphorus as well as metabolic skeletal illnesses, there is a need for knowledge of calcium and phosphate metabolism.

The skeleton serves as a reserve for the maintenance and control of calcium and phosphorous. It holds more than 98% of the body's calcium and 90% of its phosphorus. These macro-elements play crucial roles in cells and bodily fluids. Dietary calcium intake, urine formation, loss in feces, and a balance between bone growth and bone resorption all contribute to calcium balance. Intestinal absorption control calcium intake and urine is the main method of excreting extra calcium released by bone resorption.

The bone, parathyroid, and kidneys play important roles in the highly exact homeostatic regulation of serum calcium levels.

Calcium present in the blood accounts for 3 to 7% of the canine sting cardiac output. A mobilizable calcium pool in bone and serum calcium appears to be in equilibrium. Its equilibrium level is between 5 and 7 mg in parathyroidectomized animals compared to 10 to 11 mg in healthy ones. It is likely that a "feedback" mechanism controls the production of parathyroid hormone, which in turn regulates the level of equilibrium between blood and mobilizable bone calcium. The kidneys absorb a substantial portion of the dietary phosphorus before excreting it. The latter appears to be the primary organ for controlling the balance of phosphorus. The requirements of the cellular membrane are severely affected in cases of severe phosphorus deficiency. The skeleton suffers as the needs of the cellular soft tissues are addressed, which leads to severe osteoporosis. The teeth are largely undamaged, but the bones, especially the ribs, and vertebrae, become extremely thin and deficient in minerals.

Trace Elements

In dietary dry matter, trace elements that are necessary for animal nutrition are typically required at doses of 100 mg/kg. Zinc (Zn), copper (Cu), selenium (Se), chromium (Cr), cobalt (Co), iodine (I), manganese (Mn), and molybdenum (Mo) are vital trace elements for the animal body. Although these substances make up only 0.02% of the overall weight of the body, they have important functions such as serving as the active sites of enzymes or as minute amounts of bioactive chemicals. Reduced enzyme activity is one of the main effects of trace element deficiency. The lack of a single trace element, however, is frequently not linked to any particular clinical sign and instead manifests as a collection of different symptoms because each trace element is connected to so many enzymes.

Fluid, Electrolyte and Biochemistry of Vision

Fluid intake and output, total body water distribution in intracellular and extracellular fluids.

- Body fluids are made up of blood plasma, water, cellular components, solid particles, electrolytes, proteins, and other soluble substances in the body generally referred to as solutes.

- Extracellular and intracellular compartments are the two major areas where body fluids are found.
  Intracellular fluids (ICF) are body fluids made up of electrolytes, proteins, solutes, and water found inside the cell of a living organism. An important electrolyte in ICF is potassium. ICF is very important to the function of the body. It accounts for 60% of body fluid and it is 40% of total body weight.

- Conversely, extracellular fluids (ECF) are found outside the cells. The important electrolyte is sodium. Osmosis helps to regulate the movement of water in and out of the extracellular space.
- Furthermore, ECF can be a vascular fluid (found in vessels) in veins, arteries, capillaries and lymphatic tissues. Intravascular

fluid is very crucial in the maintenance of overall body fluid balance.

- Hypovolemia results from loss of intravascular fluids. This may be caused by diarrhea, severe bleeding, severe burns, vomiting, and inadequate intake of oral fluids.
- In severe cases of body fluid loss, there is hypotension, which may result in hypovolemic shock, loss of perfusion of vital organs and cellular death due to hypoxia.
- Another important ECF is the interstitial fluid (fluid not in vascular tissue but found between cells). Edema is an accumulation of excess interstitial fluid.
- Other fluids called transcellular fluids are found in the synovium, gastrointestinal system, intrapleural and cerebrospinal spaces.

Electrolytes are minerals within the cells carrying an electric charge. They are present in the blood, urine, tissues, and other body fluids. Even though the body contains a number of electrolytes, the six mentioned below are the most crucial for proper body functioning: Na^{2+}, K^{+}, Cl^{-}, $HCO3^{-}$, Ca^{2+}, and PO_4^{3-}.

Electrolytes are obtained from ingested feed and drinks. Electrolyte levels in the body can go unduly low or high whenever there is a shift in the body's water balance. The amount of water that is consumed and lost must remain in equilibrium.

Dehydration occurs when the body loses more fluids than is taken in. It may be caused by profuse sweating, vomiting, diarrhea and not taking enough fluids. The symptoms of dehydration include thirst, tiredness, dry skin and sunken eyeballs. There are two types of dehydration: hypovolemic and isotonic dehydration.

To correct dehydration, intravenous (IV) fluids are infused as soon as possible. While preparing the IV infusion, oral rehydration solution (ORS) should be administered orally if the patient can swallow. The ideal IV fluid is Ringer's lactate because it contains sodium, chloride and

potassium as well as lactate. This maintains acid-base balance similar in osmolality with that of blood.

Roles of Electrolytes

The electrolytes are involved in movement between compartments, buffering body fluids, hormonal secretion, membrane permeability, and nerve reflexes. Excretion of electrolyte occurs mainly through the kidneys, with trace amounts being lost through sweat and faeces. In particular, Na^+ and Cl^- may be remarkably eliminated because of excessive sweating. Severe emesis or diarrhea will cause a loss of Cl^- and HCO_3^-. The body can modify the respiratory and renal functions to regulate the levels of these electrolytes in the ECF. The fluid balance in the body is tightly monitored. Based on the quantity and composition of body fluids, the kidneys could indeed adjust the concentration of urine. When high levels of dehydration are detected, the thirst sensation is heightened to encourage fluid intake.

Minerals

Iron is an essential mineral found in every cell in the body and it is vital for both physical health and mental well-being.

Types of iron and their sources:

i. Haeme iron, derived from hemoglobin and myoglobin, is found in meat tissue only. It is well absorbed in the duodenum and upper jejunun and its average absorption rate is about 25%.

ii. Non-haeme iron is derived mainly from cereals, legumes, fruits, and vegetables**.** It is not as well absorbed in the intestine as heme iron and is affected by both the iron status of an individual, and components in foods eaten at the same time. Generally, its absorption is less than 5%. Vitamin C can increase the absorption of iron by two to three folds more. The body's stores of iron are evenly distributed, with 60–70% found in hemoglobin, 15–30% in the liver, 4% in myoglobin, and 0.1% in blood plasma as transferrin (a protein that transports iron in the body). It is also found in the reticuloendothelial system, ferritin (a protein found in the blood that stores and regulates iron storage in the

body) and haemosiderin (a form of iron stored in the body. It can be found in the liver, spleen, bone marrow and other tissues).
Biochemical functions: (1) transferring oxygen from the lungs to the body's other organs, (2) adequate immune system functioning, (3) promote energy production, (4) growth, both physical and mental, (5) it is part of the Cytochrome P450 superfamily and catalase which metabolizes drugs and detoxify hydrogen peroxide.

Deficiency of iron in the body could result in anaemia, a very common condition in piglets and some GIT distrubances and bleeding. Overloading with iron eventuates when absorbed iron surpasses excreted iron. Large ferritin and hemosiderin deposits are associated with haemochromatosis.

"**Carotenoids**" is a generic term used to designate most pigments naturally found in animal and plant kingdoms. Vitamin A exists as a provitamin in vegetables (i.e., β-carotene). Most carotenoids are tetraterpenoids (C40) consisting of 8 isoprenoid units linked so that the molecule is linear and symmetrical, with the order reversed in the center.

Provitamin A carotenoids are converted into vitamin A (retinol) in the liver or intestine. In vertebrates, Vitamin A exists in three oxidation states: retinal, retinol, and retinoic acid (retin A). Vitamin A is critical not only for vision but also for gene regulation in the form of all-transretinoic acid (RA), which binds ligand-activated transcription factors such as retinoic acid receptors (RARs) and retinoid X receptors.

Also, in the intestinal mucosa of all mammals, retinal is reversibly reduced to retinol by a specific zinc-dependent retinal reductase which uses NADH or NADPH as a coenzyme. This enzyme is present in the rod and cone photoreceptors.

Retinol formed in the GIT mucosal cells is esterified to fatty acids and packaged into chylomicrons. Vitamin A appears to behave in a similar

manner as steroid and thyroid hormones, and certain proteins may be under dual control (by both triiodothyronines, T_3, and Vitamin A).

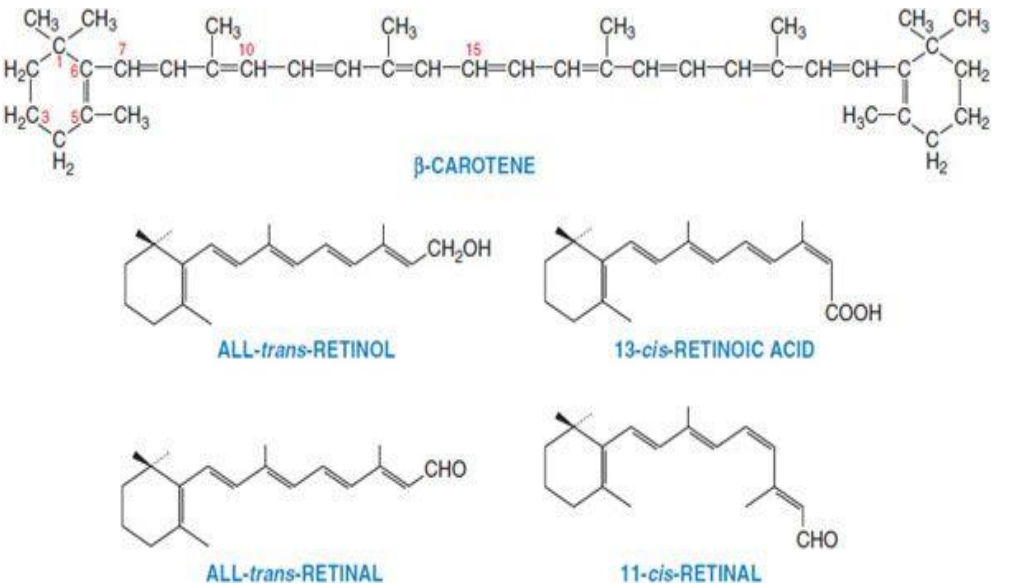


Figure 3: Showing the structure of beta carotene, retinol, retinal, retinoic acid, and retinal.

Exercise

1. Differentiate between cis and trans fatty acids.
2. Distinguish between metabolism, catabolism and anabolism.
3. List various sources of acetylCoA. What is the significance of acetylCoA in fatty acid anabolism?
4. Describe the regulatory importance of fatty acid catabolism.
5. Of what importance is beta oxidation in fatty acid metabolism?
6. What are the similarities between alpha, beta and omega oxidation of fatty acids metabolism?
7. Describe the various routes through which cholesterol can be catabolized.
8. What are prostaglandins?

9. Name the precursor of PG.
10. What is the effect of PG on the uterus?
11. List the factors affecting nutrients' requirement.
12. What are the four basic components of nutrient requirement?
13. Differentiate between BMR and SDA.
14. List the important factors contributing to obesity.
15. What are the hormones that respond to increased fat stores?
16. Why are piglets prone to iron deficiency?

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Chapter 9

VBC 204: Introductory Molecular Biology

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Overview

The area of biology known as molecular biology is concerned with the molecular underpinnings of biological activities. Since both living and non-living things are composed of chemicals, molecular biologists investigate how molecules interact in living things to carry out their essential functions. This involves the proper understanding of subcellular, molecular mechanisms underlying cellular activities including DNA structure, protein synthesis and means by which cells replicate and multiply. Genetic engineering is applied in medicine for the diagnosis, monitoring, treatment, control and prevention of several animal and human diseases. Knowledge of the chemistry and structure of nucleic acids, nomenclature of bases, nucleotides and nucleotide biosynthesis and or metabolism in general is of paramount importance to Veterinary students. The applications of genetic engineering in veterinary medicine and research on the common diseases as well as abnormalities caused by free radicals and the search for natural or synthetic remedies for the treatment and management of such conditions are among the unique aspects of veterinary biochemistry.

Objectives

The objectives of this course are to:

i. explain the background and key concepts in molecular biology;

ii. describe the principles and explain the interrelationships among structures, processes and molecular mechanisms that underlie the activities of a normal cell;
iii. provide knowledge of basic techniques in cell and molecular biology; and
iv. explain the potential applications of molecular biology in veterinary medicine.

Subcellular and Molecular Mechanisms Underlying Cell Activities Including DNA Structure, Protein Synthesis and Means by Which Cells Replicate and Multiply.

What is Molecular Biology?

Molecular biology refers to the area of biology that involves the understanding of the structures and compositions of cellular molecules (e.g., nucleic acids and proteins), as well as the interactions that occur among them. These molecules are responsible for carrying out the biological processes required for cellular functions and maintenance of life.

Subcellular and molecular basis of cell function

The smallest functional unit of living things is referred to as a cell. The concept of genetic transfer of information through the DNA to RNA and synthesis of proteins is the major molecular biology hallmark that is generally referred to as the "central dogma" of molecular biology (Figure 1).

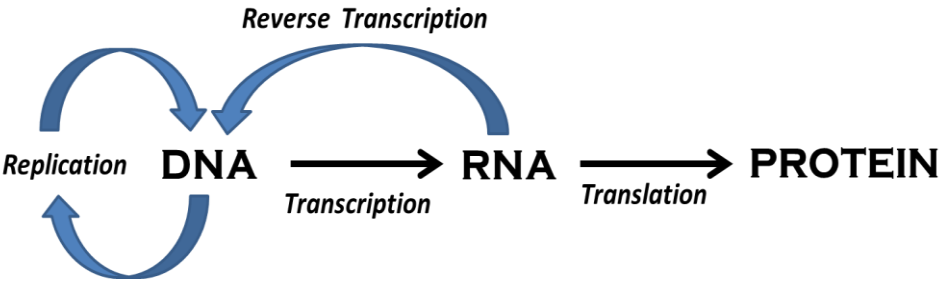


Figure 1: Genetic information flow (basic principle of molecular biology)

Definition of terms

Deoxyribonucleic acid (DNA): is the double-stranded nucleic acid macromolecule in single-celled and multicellular organisms which contains the genetic information or 'code' needed for all kinds of biochemical functions carried out in the cell. However, the genetic material in viruses is either DNA or RNA.

Ribonucleic acid (RNA): is a nucleic acid with single strand that contains uracil in place of thymine. Three types of RNA are transcribed from DNA and these include messenger RNA, transfer RNA and ribosomal RNA.

Gene: A short DNA section containing elements that code for a transcribable unit (a functional RNA or protein product) as well as a non-transcribable unit (i.e. elements encoding regulatory regions).

Genome: The sum total of an organism's genetic information.

Chromosome: This refers to strands of DNA packaged together with specific proteins (histone proteins).

Chromatin: The diffuse, extended state of the chromosomes during the resting (non-actively dividing) phase of the cell cycle.

Chromatid: The form of chromosomes during the actively dividing phase of cells where the structures are condensed and visible under the light microscope.

Nucleotide: the basic unit of nucleic acid composing of a nitrogenous base, pentose sugar (deoxyribose or ribose in DNA and RNA, respectively) and a phosphate group.

Nucleoside: A nucleoside consists of a nitrogenous base attached to pentose sugar. It is different from nucleotide because of the absence of a phosphate group in the nucleoside.

Cell cycle: The series of cellular events that essentially incorporates the processes of growth and division of cells. The cell cycle consists of two phases including interphase (phase of cell growth, DNA replication and preparation for cell division) and mitosis (actual phase of cell division)**.**

DNA replication: The process by which the entire genome of an organism is copied or duplicated prior to cell division.

Transcription: The process of synthesizing mRNA copy from a gene sequence in DNA.

Translation: The process by which the coded information in mRNA is interpreted to produce an amino acid sequence in a protein during protein synthesis

Inheritance: This term is used to describe the passing of genetic information from one set of parents to their offspring through the combination of genetic information of the spermatozoon and ovum.

Genetic engineering and gene splicing

Genetic engineering is a broader term that encompasses a range of methods and techniques that allow the manipulation of heritable genetic material leading to the formation of new sequences of recombined genetic elements.

Gene splicing is a specific technique used in genetic engineering. It is the process of excising or cutting and recombining DNA fragments to create a new genetic sequence.

Methods of gene splicing and genetic engineering

1. Mechanical shearing: By its physical nature, the DNA molecule can be cleaved by shear forces in solution.
2. Non-specific enzyme (endonucleases) digestion: In the absence of mechanical shearing facilities, non-specific endonucleases such as *DNase I* can be used to cleave the DNA molecule in a random fashion.
3. Restriction enzyme digestion: The discovery of host-controlled restriction and modification (HCRM) involving specific endonucleases (restriction endonuclease or enzyme) in the 1970s provided a way of cutting DNA molecules in a non-random fashion.
4. DNA ligase: After cutting the DNA into fragments using restriction enzymes, DNA ligases are used to precisely ligate or join fragments of interest into a single DNA molecule.
5. CRISPR/Cas9: This is a revolutionary gene editing technique that allows the introduction of precise changes to a DNA molecule.
6. Transformation: Transformation is the process of introducing a foreign DNA, often an engineered DNA molecule, into a host cell. There

are several techniques used in transformation in higher eukaryotes. Techniques used for transformation include:

i. Microinjection - a fine needle is used to inject DNA directly into the nucleus of individual cells and embryos.
ii. Electroporation – this involves the application of an electric field to cells that creates small pores in the cell membrane.
iii. Shooting (with a ballistic gun) – this involves the coating or conjugation of a DNA molecule with a tiny metal particle such as gold and then shooting the conjugated DNA into the cell using a ballistic or gene gun.
iv. Lipofection - For the gentle and highly efficient transfection of several types of eukaryotic animal cells, a synthetic cationic lipid-based compound is used.

Applications of genetic engineering in veterinary medicine

Disease prevention: Genetic engineering techniques have allowed the emergence of alternatives to classical vaccines.

Disease diagnosis: Many diseases of different etiology can be diagnosed with the aid of polymerase chain reaction (PCR). The PCR can be used for the detection of the genetic material of infectious agents from routine clinical samples such as blood.

Treatment: Gene therapy, which involves the transfer of genetic material to a patient's cell to cure a genetic disorder has been used to successfully treat dogs with Duchenne muscular dystrophy.

Animal production: Advances in genetic engineering techniques have allowed the generation of transgenic animals.

Chemistry and structure of nucleic acids, nomenclature of bases, nucleotides and nucleotide biosynthesis

Components of Nucleic acids: The polymers of nucleotides (polynucleotides) are called nucleic acids and are bound together by 3' and 5' phosphate bridges.

Nucleotide: A pentose sugar, a phosphate group and nitrogenous base make up a nucleotide.

Structure of nucleotides: The nucleotide fundamentally comprises of nucleobase, sugar, and phosphate. A base and a sugar constitute a nucleoside. Hence, a nucleotide is a combination of a nucleoside and a phosphate.

Purine and pyrimidine

Nucleotides and by extension, nucleic acids contain aromatic heterocyclic compounds as their nitrogenous bases. Purines and pyrimidines are the two different types of bases. Fig 2 shows a generic representation of their structures.

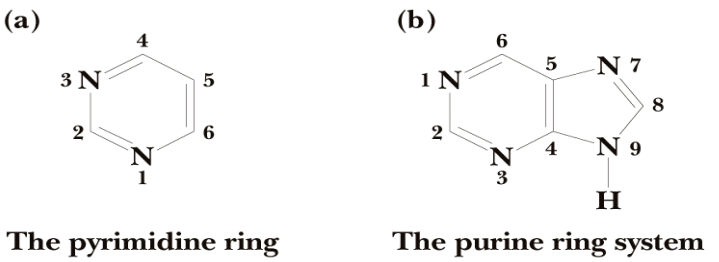


Figure 2: Nitrogenous bases (A) Pyrimidine (B) Purine (general structure). The positions are numbered in accordance with international system.

Bases are nitrogenous. The hydrolysis of nucleotides results in two types of compounds, purines and pyrimidines, which contain heterocyclic rings. These are referred to as purine and pyrimidine bases. Figure 2 depicts their chemical structures and the numbering of the components in the molecule. Purines are formed by adding an imidazole group to pyrimidines. All the atoms in purines and pyrimidines are in the same plane.

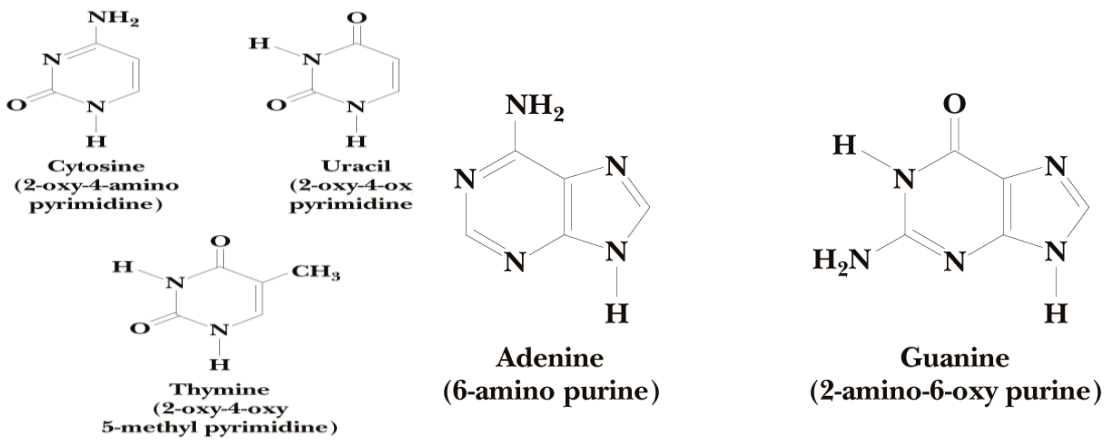


Figure 3: Major structures of pyrimidines and purines: adenine (A) and guanine (G) are purines while thymine (T), cytosine (C) and uracil are pyrimidines.

Nucleotide nitrogenous bases are classed as pyrimidines or purines. Pyrimidines, which include uracil, thymine, and cytosine, are heterocyclic amines having two nitrogen atoms in a six-member ring. Purines are heterocyclic amines made up of a pyrimidine ring fused to a five-member ring containing two nitrogen atoms. The primary purines present in nucleic acids are adenine and guanine (Figure 3).

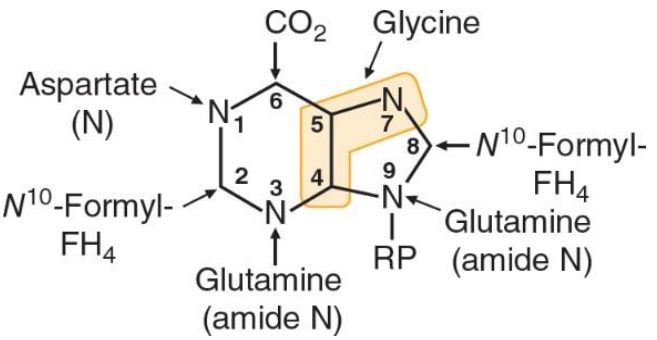


Figure 4: The origin of purine ring atoms.

The N_3, N_9 originated from glutamine amido group, N_7, C_5, C_4 are derived from Glycine, C_6 is derived from CO_2, amino group of aspartate contributed N_1, N^{10} of tetrahydrofolate also contributed C_2 and C_8.

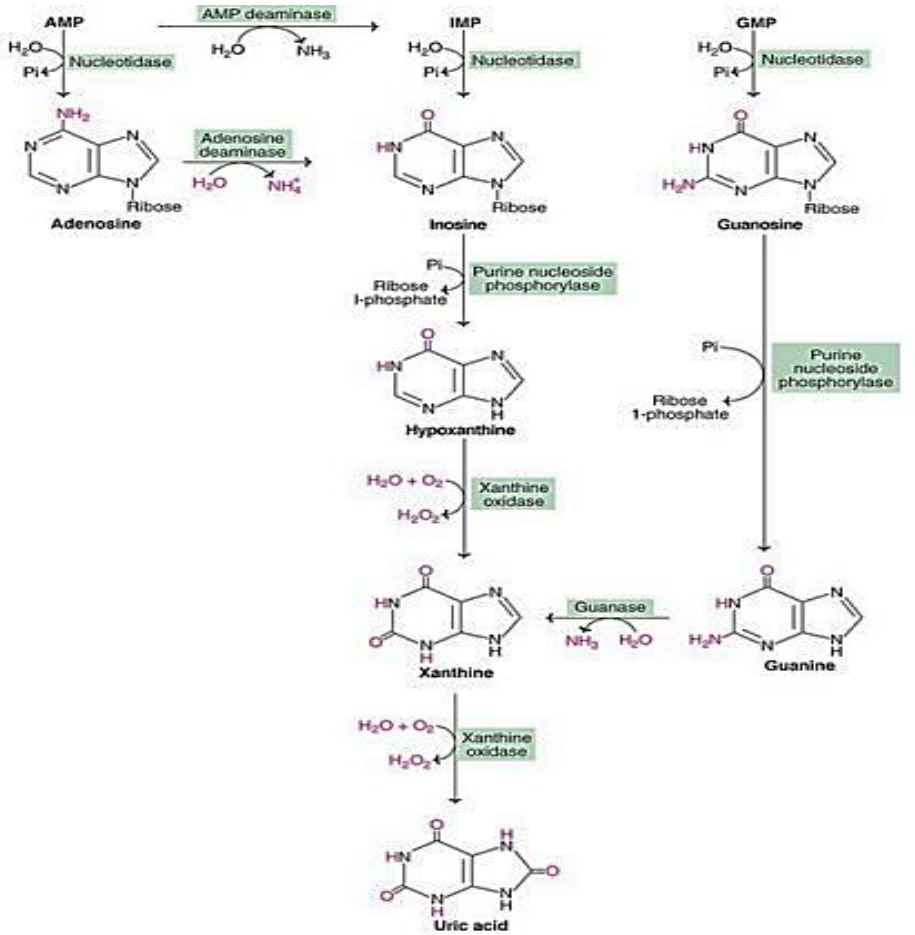


Figure 5: Break down of purine nucleotide to uric acid.

Pathways of purine nucleotide catabolism

1. Conversion of nucleotide monophosphate such as AMP, IMP and GMP to their corresponding forms - adenosine, inosine and guanosine - is catalyzed by the enzyme nucleotidase.
2. Removal of the amino group from AMP or adenosine forms IMP or inosine, rspectively.
3. Purine nucleoside phosphorylase converts inosine and guanosine to hypoxanthine and guanine (purine bases). Since this enzyme does not breakdown adenosine, it must be transformed to inosine.
4. Deamination of guanine by the enzyme guanase yields xanthine.
5. Conversion of hypoxanthine to xanthine, and xanthine to uric acid is catalyzed by the enzyme xanthine oxidase.

Purine biosynthesis

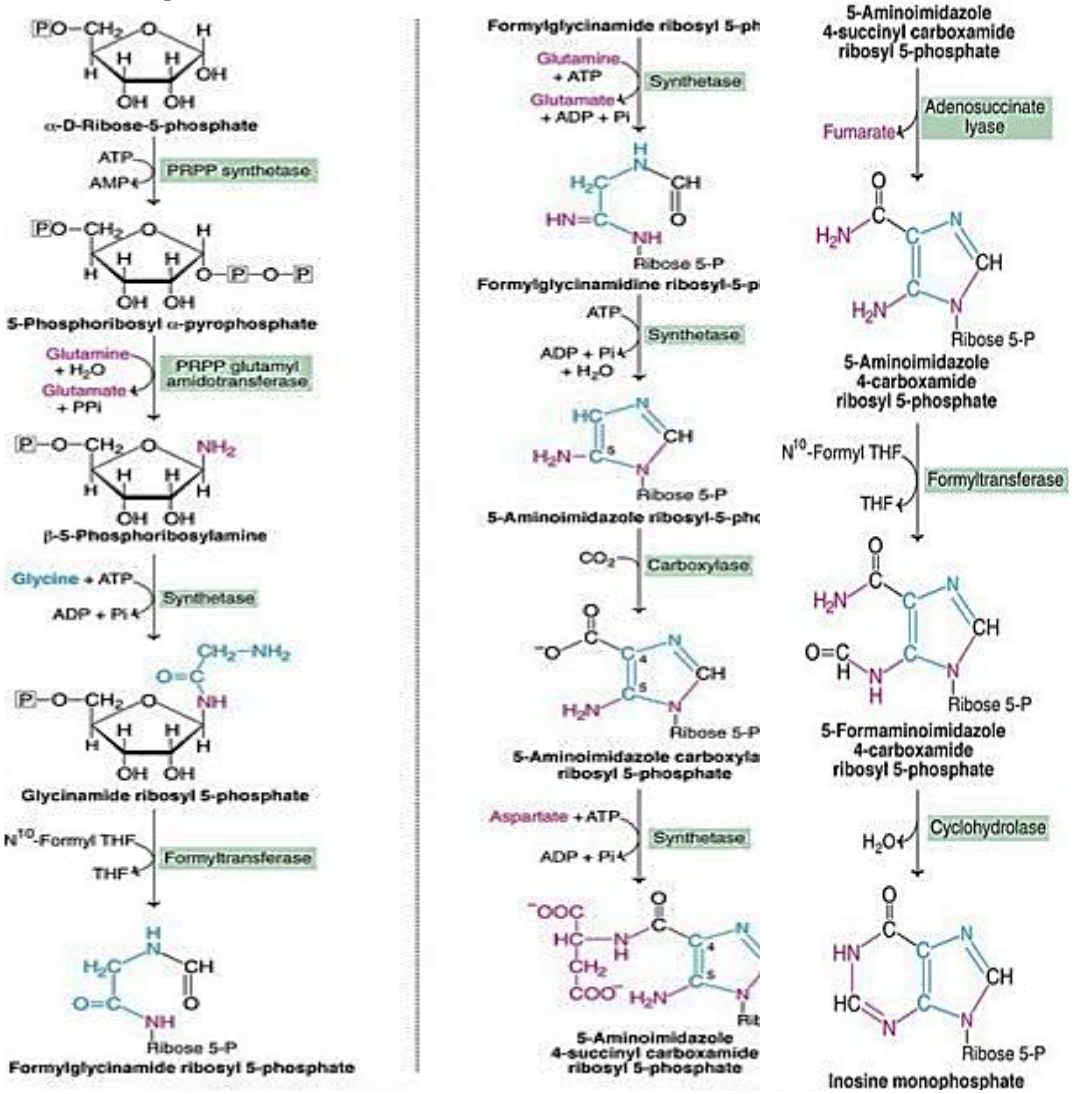


Figure 6: The pathway for the synthesis of inosine monophosphate.

Pathway of purine nucleotide synthesis

1. Purine nucleotide synthesis begins with ribose 5-phosphate, which is formed during the hexose monophosphate shunt of carbohydrate metabolism. To produce phosphoribosyl pyrophosphate (PRPP), it combines with ATP.
2. To make 5-phosphoribosylamine and substitute pyrophosphate, glutamine transfers its amide nitrogen to PRPP. Nucleotide feedback inhibition (IMP, AMP, and GMP) regulates the PRPP glutamyl amidotransferase enzyme. The 'committed step' in purine nucleotide biosynthesis is this way.
3. In the presence of ATP, phosphoribosylamine and glycine combine and produce glycinamide ribotide GAR (glycinamide ribosyl-5-phosphate).
4. N^{10}-formyl tetrahydrofolate donate formyl group which results in the formation of formyl glycinamide ribosyl 5-phosphate.
5. Amido group from glutamine was transferred to formyl glycinamide to form formyl glycinamidine ribosyl-5-phosphate.
6. A 5-amino-imidazole ribosyl-5-phosphate is formed by imidazole ring closure in ATP-dependent reaction.
7. Addition of CO_2 results in the formation of amino-imidazole carboxylate ribosyl-5-phosphate. Unlike other carboxylation processes, this one does not need the vitamins biotin and/or ATP.
8. The product of step 7 reaction combines with aspartate and yields amino-imidazole-4-succinyl carboxamide ribosyl-5-phosphate.
9. Breakdown of fumarate by adenosuccinate lyase results in the formation of amino-imidazole-4 carboxamide ribosyl-5-phosphate, leaving aspartate amino group.
10. One carbon moiety was transferred from tetrahydrofolate resulting in the production of forma-amino-imidazole-4-carboxamide ribosyl-5-phosphate.
11. The last reaction catalyzed by cyclohydrolase results in ring closure and water molecule removal leading to the formation of inosine monophosphate (IMP).

AMP, GMP from IMP and the formation of purine nucleoside di- and triphosphate

AMP and GMP are initially synthesized from inosine monophosphate (IMP) (Fig.7). Inosine monophosphate is the first step in the synthesis of AMP and GMP (Fig. 7). In the presence of GTP, aspartate condenses with IMP to generate adenylsuccinate, which cleaves to form AMP.
IMP is dehydrogenated by NAD^+ to generate xanthosine monophosphate (XMP), which is then used to synthesize GMP. Glutamine then transfers amide nitrogen to XMP, resulting in GMP.
To participate in most metabolic processes, nucleoside monophosphates (AMP and GMP) must be transformed to the equivalent di- and triphosphates. This is achieved by the phosphate group transfer from adenosine triphosphate catalyzed by nucleoside mono- and diphosphate kinases (Fig. 8).

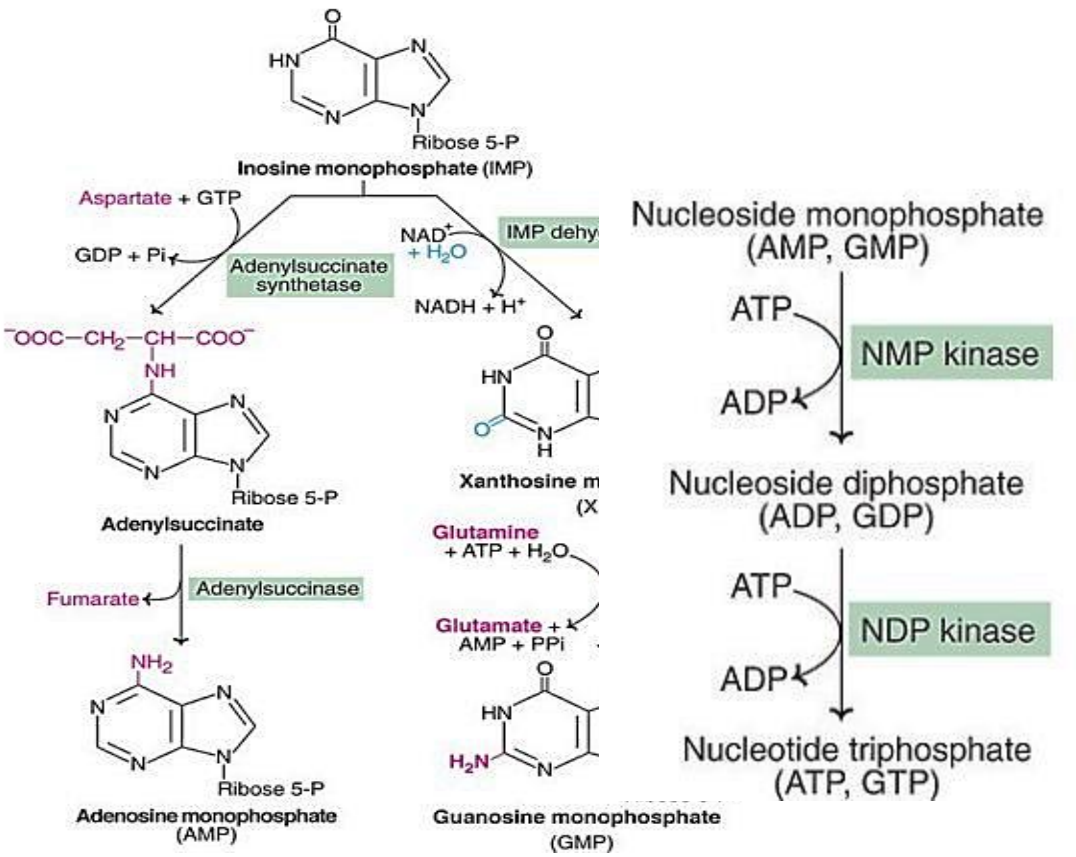


Figure 7. Inosine monophosphate is used in the synthesis of AMP and GMP.

Figure 8. Conversion of nucleoside monophosphates to di- and triphosphates.

Salvage pathway of purine biosynthesis

During the normal nucleic acid cycle, free purine such as adenine, guanine and hypoxanthine are produced. They can also be obtained from dietary sources. The nitrogenous base purine can be transformed into the nucleotide equivalent through a salvage pathway.

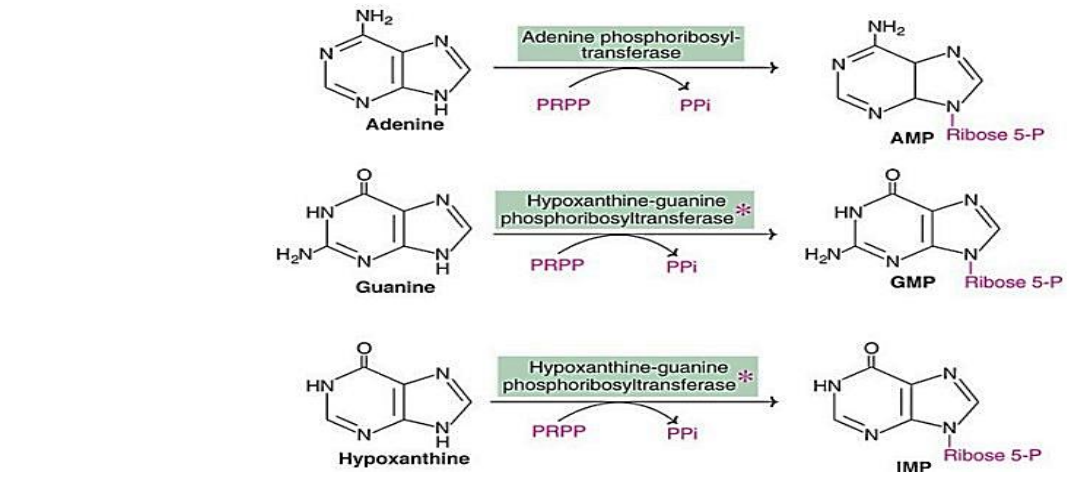


Figure 9. Salvage pathway of purine nucleotide synthesis.

Conversion of ribonucleotide to deoxyribonucleotide

Reduction at C2 of the ribose sugar of ribonucleotide (Fig. 10) yields the deoxyribonucleotide form of purines and pyrimidines. The enzyme, ribonucleotide reductase, speeds up the rate of this reaction.

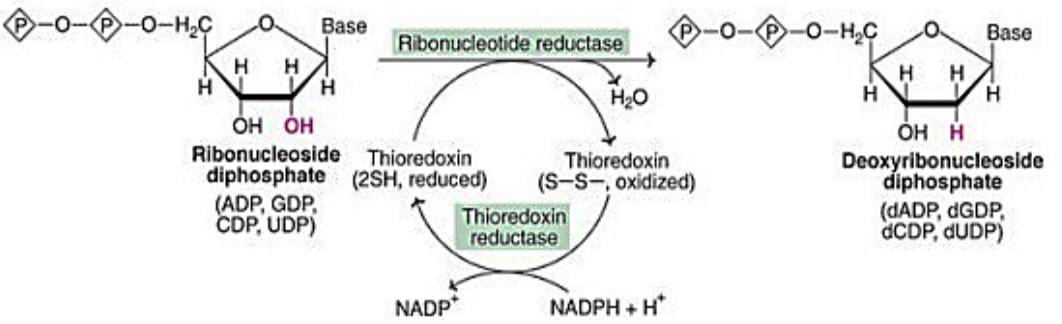


Figure 10. Deoxyribonucleotide synthesis from ribonucleotides.

Biosynthesis of pyrimidine ribonucleotides

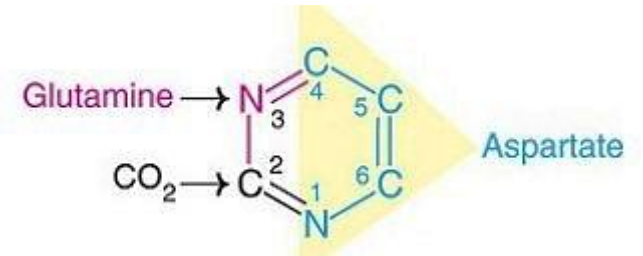


Figure 11: Sources of individual atoms in pyrimidine ring.

To form carbamoyl phosphate, glutamine transfers its amido nitrogen to CO_2 catalyzed by carbomoyl phosphate synthetase.
Carbomoyl phosphate reacts with aspartate and yields carbamoyl aspartate. Aspartate in the presence of NAD+ orotate if formed from carbomoyl aspartate.
Orotate combines with ribose 5-phosphate to form orotidine monophosphate (OMP) catalyzed by orotate phosphoribosyl transferase.
Decarboxylation of OMP results in uridine monophosphate (UMP).
UMP is transformed to UDP via an ATP-dependent kinase process which acts as a source for the synthesis of deoxyuracil monophosphate, deoxyuradil monophosphate, deoxythymidylate monophoshate, etc via a reaction catalyzed by ribonucleotide reductase.
Ribonucleotide reductase is a thioredoxin-dependent enzyme that converts UDP to dUDP.
The transfer of methyl group from N5 and N10 methylene tetrahydroforlate to produce deoxythymidine is catalyzed by thymidylate synthatase.
UDP is phophorylated by ATP kinase to form UTP. Amination is used to generate CTP from UTP catalyzed by CTP synthetase with nitrogen donated by glutamine.

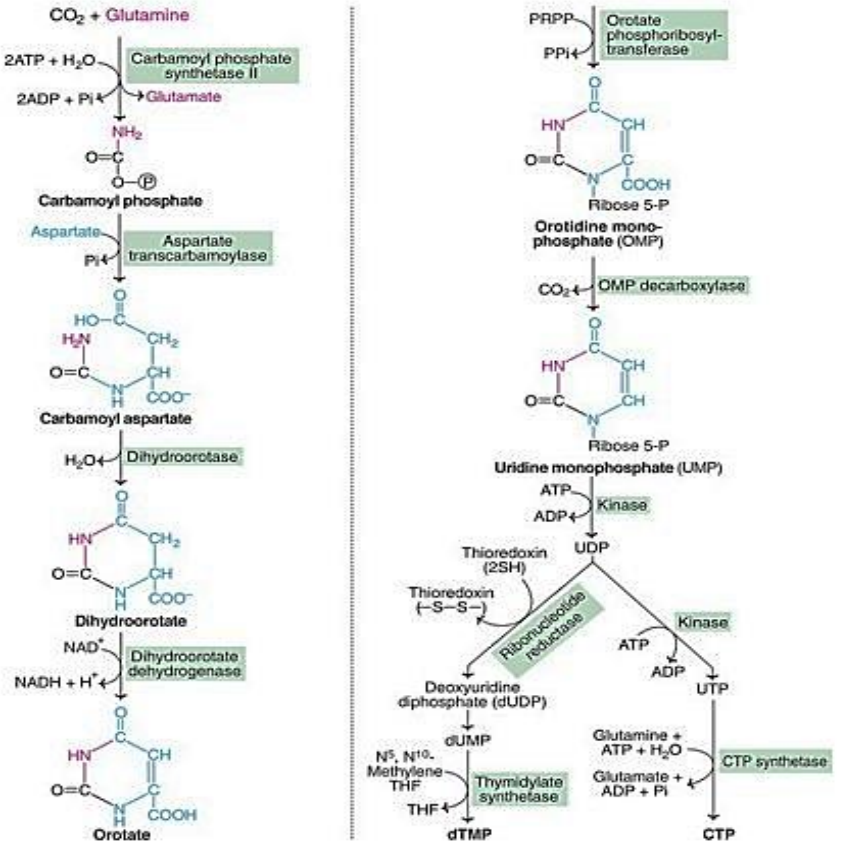


Figure 12: Pathway of pyrimidine biosynthesis.

Regulation of pyrimidine synthesis: Aspartate transcarbomoylase (ATCase) catalyzes the rate limiting step of pyrimidine biosynthesis in bacteria.

Degradation of pyrimidine nucleotides: Pyrimidine nucleotide like purine nucleotide undergoes dephosphorylation, deamination and glycosidic bond breakage to yield free nitrogenous bases such as cytosine, uracil and thymine.

Salvage pathway: Similar to purines, pyrimidines can also be used as precursors in the salvage route to synthesis the corresponding nucleotide.

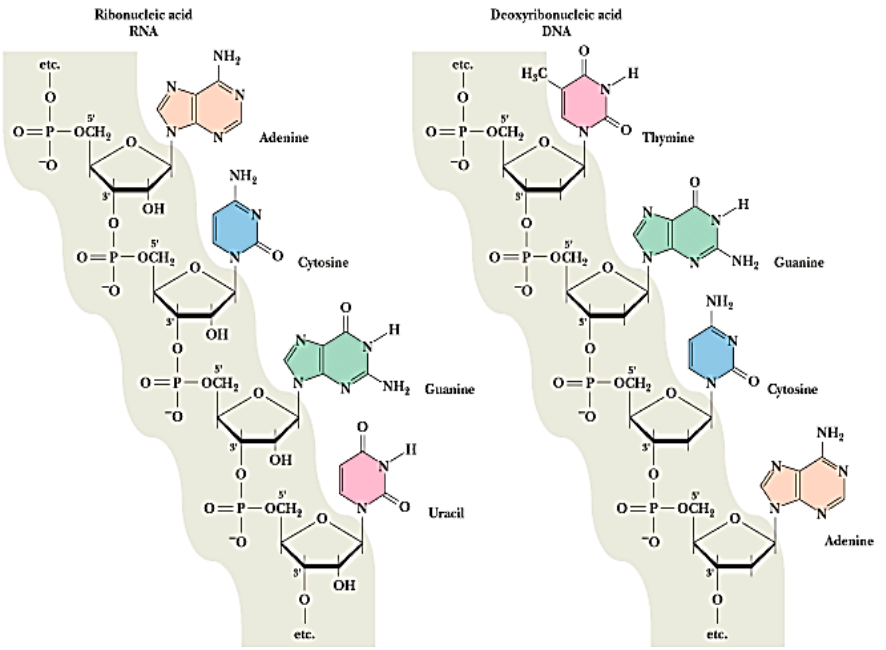
Composition of DNA and RNA, the Watson-Crick DNA double helix

DNA structure

The polymer of deoxyribonucleotide simply known as deoxynucleotide makes up the DNA. The building blocks include deoxyadenylate (dAMP), deoxyguanylate (dGMP), deoxycytidylate (dCMP) and deoxythymidylate (dTMP).

In 1953, J. Watson and F. Crick discovered the DNA double helix structure. This is in line with the discovery of modern molecular biology. The DNA structure is similar to that of a twisted ladder. (Fig. 13).

Diagram of polynucleotide



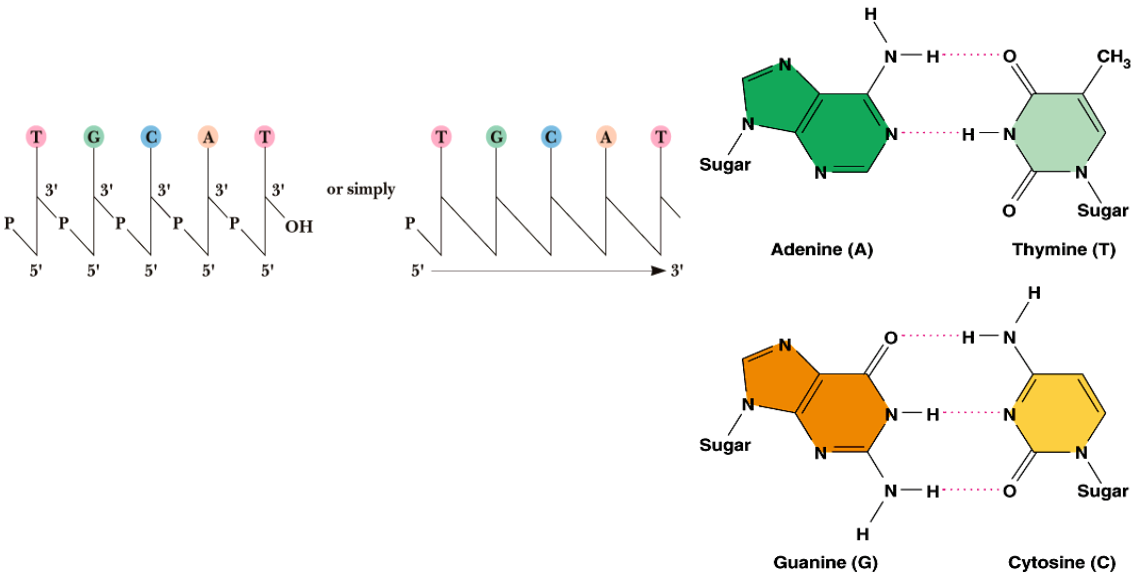


Figure 13: Structure of DNA showing complimentary base pairing.

Conformations of double helix: the DNA's double helix occurs in not less than six distinct types (A, B, C, D, E and Z) with the most significant type being A, B and Z.

Functions of nucleic acids: In principle, RNA molecules are capable of carrying out the cellular functions of gene storage and transfer of genetic information that are carried out by DNA.

Replication of DNA: refers to the process by which DNA duplicates itself to produce identical DNA molecules.

Prokaryotic DNA Replication

In prokaryotic animals, DNA replication is semiconservative:

In the parent DNA, each of the two strands are complimentary to each other. The parent DNA has two strands complementary to each other. Replication of both strands results in the formation of two daughter molecules. Each freshly synthesized DNA molecule has a strand from

the parent DNA and another one from the newly synthesized DNA (Fig 8).

DNA helicases: At the replication fork, the enzyme helicase binds to both DNA strands. Helicases move up and down the DNA helix, separating the strands.

Okazaki fragments: are short pieces of DNA that are synthesized on the lagging strand.

Transcription

Is the process of synthesizing an RNA copy from the DNA sequence of a gene. It differs from replication in which DNA is synthesized from DNA.

Three types of RNA formed by transcription:

a. RNA that carries the message that will be translated to protein, referred to as messenger RNA (mRNA).
b. RNA that forms part of the ribosome during protein synthesis, referred to as ribosomal RNA (rRNA).
c. RNA that transports amino acid from the cell cytoplasm to the ribosome, referred to as transfer RNA (tRNA).

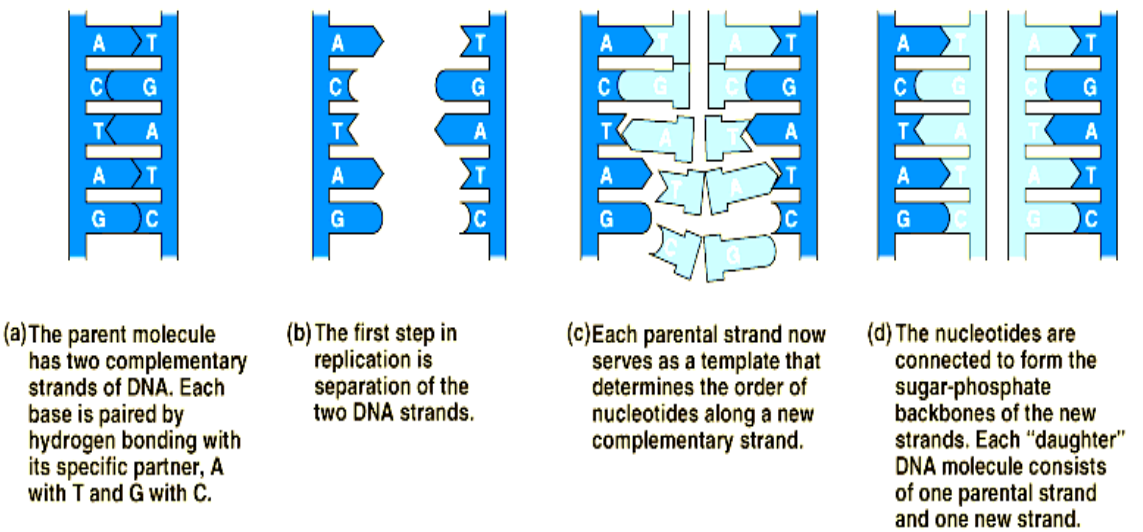


Figure 14: DNA replication.

Table 1 Comparison of 3 types of RNA

Comparison of Three Types of RNA			
Name	**mRNA**	**rRNA**	**tRNA**
Function	Carries genetic information from DNA in the nucleus to direct protein synthesis in the cytoplasm	Associates with protein to form the ribosome	Transports amino acids to the ribosome
Example			

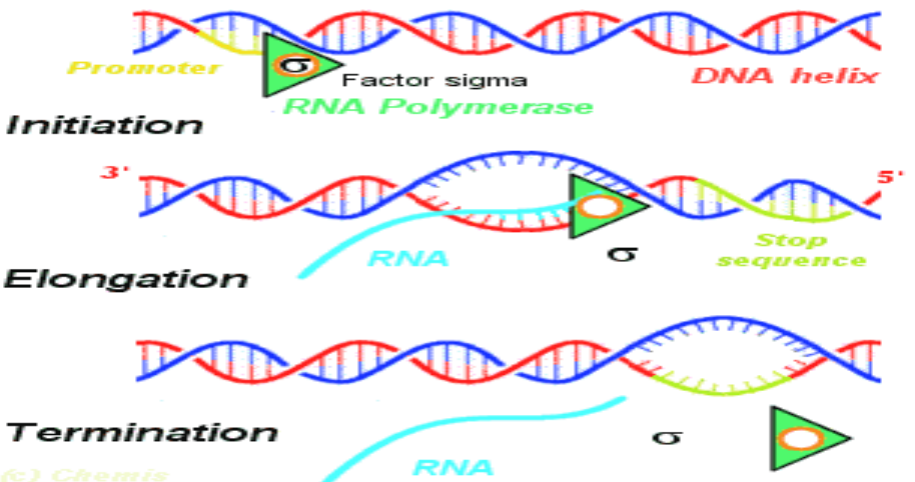


Figure 15: Transcription of RNA.

(a) Nucleotides are linked together by RNA polymerase.
(b) The DNA strands unwind during transcription.
(c) The strand of RNA is detached from that of DNA after transcription.

Steps involved in transcription

1. Initiation: RNA polymerase unzips DNA and separates it into 2 strands.
2. Elongation: RNA nucleotides are added to the DNA strands.
3. Termination: RNA synthesis continues until it reaches the region called a stop sequence or termination sequence.
4. RNA polymerase releases new RNA synthesized and DNA.

TRANSLATION

(a) Codon refers to the base code in DNA or mRNA.
(b) They are coded in threes.
(c) Single amino acid corresponds to triplet code.

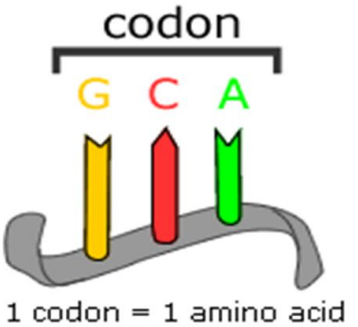


Figure 16: Interpretation of the mRNA codon sequence.

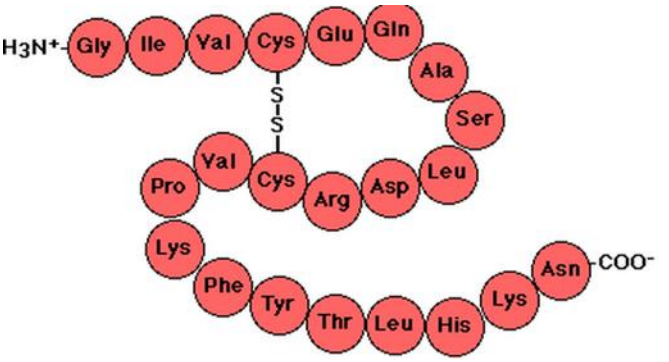


Figure 17: Long polypeptide form

Genetic regulation of metabolism

Metabolic (anabolic and catabolic) pathways in the animal body are rigidly controlled in a way that physiological demands of the body/cell are met as at when and how each product of the pathways are needed, both on the long and short term.

Regulation of gene expression: Gene expression refers to the process of translation of DNA transcripts in the form of mRNA to proteins.

Chromatin Structure: The DNA in animal cells exists in complex with proteins called chromatin, which varies in level of condensation.

Acetylation and deacetylation of histones: Genes can be activated by the acetylation of histones (proteins around which the genes are wrapped) while the deacetylation of the histones represents inactivation of the gene expression process.

Methylation of DNA: When the cytosine nucleotide of DNA is methylated to methylcytosine, the DNA or gene becomes inaccessible to transcription factors and thus such genes are repressed.

Enhancers: Gene activators or enhancers are DNA molecules that enhance gene expression by providing binding sites for positive promoters of transcription (transcription factors).

Protein Motifs: Helix-turn-helix motifs as regulators of gene expression.
Gene Amplification: is the process used to increase the expression of particular gene while in gene rearrangement, DNA is rearranged to produce new gene products (such as in the production of specific antibodies for particular antigens) through the transposition of genes or somatic recombination of DNA.

Introduction to Genetic Engineering in Veterinary Medicine

Genetic engineering, which is also referred to as recombinant DNA technology, is biotechnology that involves the application of the knowledge of molecular biology to manipulating living organisms to create desired traits.

Tools in Genetic Engineering

Restriction enzymes: These are enzymes that cut DNA at specific sequences.
Vectors: *Plasmids* – these are a special circular piece of double-stranded DNA found in bacteria, capable of self-replicating, which can be easily removed and inserted back into the bacterial cell.

Cosmids – are another form of vector used in genetic engineering which are modified forms of plasmids that have additional cloning sites.

Bacteriophages - are viruses that infect and feed on bacteria by using the bacterium's machinery to replicate itself.
Ligases: are enzymes involved in the joining together of DNA segments by the addition of the sugar backbones of the nucleic acids to each other.

Techniques in Genetic Engineering: Genetic engineering requires the input of a donor organism that supplies genes of desired traits and recipient organisms in which the trait is to be reproduced.
Recombinant DNA Technology: In this technique, the desired DNA segments or genes are inserted into the transgenic organism such as

rapidly dividing cells of bacteria through the medium of a vector such as plasmids.

Gene Cloning:

Gene or DNA cloning refers to the production of large number of copies of specific genes or DNA fragments.

Applications of Genetic Engineering in Veterinary Medicine

1. Used in disease diagnosis and in obtaining useful information about genetic makeup of animals.

2. Production of transgenic animals with desired health or disease-resistant traits.

3. Production of proteins for treatment of deficiencies.

4. Gene therapy involves delivery of genetic materials into needed cells to affect the genetic output of that cell.

Virus and Oncogenes

Oncogenes: are genes arising from the mutation of proto-oncogenes (which are involved in regulating cell growth, division and apoptosis) and result in uncontrolled and abnormal cell division leading to the development of cancers.

Underlying genetic mechanisms associated with oncogene activation include the following:

- Point mutations, deletions, or insertions that lead to a hyperactive gene product.
- Point mutations, deletions, or insertions in the promoter region of a proto-oncogene that lead to increased transcription.
- Gene amplification events leading to extrachromosomal copies of a proto-oncogene.
- Chromosomal translocation events that relocate a proto-oncogene to a new chromosomal site leading to higher expression.
- Chromosomal translocations that lead to a fusion between a proto-oncogene and a second gene, which produces a fusion protein with oncogenic activity.

Programmed cell death

There are many forms of cell death. First, apoptosis, which is a form of tightly regulated genetically controlled self-orchestrated cell death, is often referred to as programmed cell death (PCD).

Narratives of cell death

a) Classification: Programmed Cell Death (PCD) is an active process characterized by a distinct morphological change such as cell shrinking, fragmentation, etc. known as apoptosis.
b) Initiation and Inhibition: Several different stimuli induce apoptosis. They include but are not limited to ischemia, hypoxia, exposure to certain drugs and chemicals, immune reactions, infectious agents, high temperature, radiation, and various disease states. Bcl-2, Bcl-XL, and Bcl-w are members of the family that suppress apoptosis and have all four domains.
c) Stages: Apoptotic death occurs in two stages. During the early or latent stage, the cell looks morphologically normal but is marked for death. Early apoptotic cell uptake is thought to be anti-inflammatory and causes a tolerogenic response, but late apoptotic and necrotic cell clearance is linked to inflammation and promotes immunity/autoimmunity.
d) Role of Programmed Cell Death in homeostasis: Apoptosis plays a critical role during normal development and homeostasis of adult tissues. It is a normal physiological form of cell death and therefore, plays a key role both in the maintenance of adult tissues and in embryonic development.

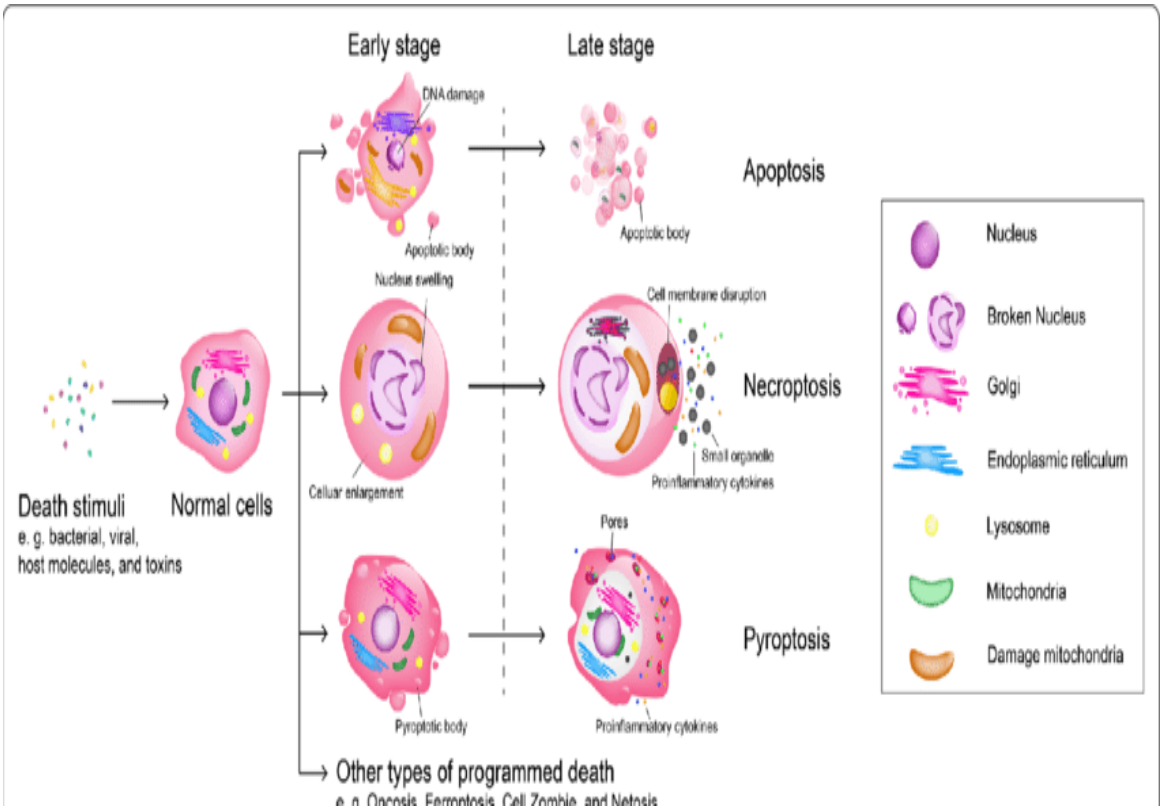


Figure 18: Cellular events in cell death (Harvard Division of Continuing Education, 2013).

e) Veterinary Clinical Correlations: Deregulation of apoptosis is commonly associated with animal diseases ranging from cancer to neurodegeneration. Also, toxicants induce cell death via apoptosis.

Biochemistry of Free radicals

Free radicals are chemical species (atom or molecule) containing one or more lone or unpaired electrons in its outer orbital and is capable of independent existence.

Interactions of major free radicals

The superoxide radical is often regarded as the primary reactive oxygen species (ROS) generated in cells and its interaction with other molecules via enzyme-catalyzed reactions produces other "secondary ROS".

Fenton reaction: $Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + \bullet OH + OH-$

***Haber-Weiss reaction*:** $O_2\bullet- + H_2O_2 \rightarrow O_2 + \bullet OH + OH-$ (Fe^{3+} generated in the Fenton reaction is reduced to Fe^{2+}).

At low concentrations, free radicals and other ROS are vital to animal health and may play beneficial roles in the following ways:

i. As part of chemicals released by immune cells (e.g., neutrophils, monocytes and macrophages) to destroy invading pathogens in disease conditions.
ii. As regulators of cellular signaling pathways.
iii. As stimulators of the mitogenic response.

On the other hand, excessive amounts of ROS and free radicals are toxic to the animal body and are capable of causing damage to critical cellular macromolecules including DNA, proteins and lipids.

Sources of free radicals in animals

Endogenous sources

These include:

i. The production of superoxide radicals in the mitochondria via the respiratory chain during transfer of electrons from complexes I (NADH dehydrogenase) and II (succinate dehydrogenase) to ubiquinone, resulting in the formation of an unstable semiquinone anion ($^{\cdot}Q^{-}$) which shunts electrons to molecular oxygen to form superoxide radicals.

ii. The production of hypochlorous acid (HOCl) in neutrophils via the enzyme myeloperoxidase which catalyzes the oxidation of chloride ions with hydrogen peroxide.

iii. The formation of superoxide radicals and hydrogen peroxide in peroxisomes via several oxidase enzymes such as xanthine oxidase, NADPH oxidase and peroxidases.

iv. The formation of the hydroxyl radical via the reaction between superoxide radical and hydrogen peroxide with Fe^{2+} or Cu^{2+} as catalyst. This reaction is commonly called the Fenton reaction.
v. The formation of nitric oxide radical ($NO^{\bullet}$) during the conversion of L-arginine to citrulline in a reaction catalyzed by nitric oxide synthase.
vi. Formation of ROS by drug-metabolizing enzymes of the endoplasmic reticulum including cytochrome P-450 enzymes.

Exogenous sources
Several exogenous processes produce ROS directly or indirectly in animals. ROS and free radicals are often produced in response to exposure to toxic agents such as drugs, environmental pollutants, heavy metals, carcinogens or other xenobiotics, as well as radiation.

Antioxidants: are substances which prevent or delay free radical reactions that could otherwise cause cellular damage.
Antioxidants within cells are generally classified as enzymatic or non-enzymatic antioxidants. The most common enzymatic antioxidants include:
1. **Superoxide dismutase (SOD):** This enzyme catalyzes the dismutation (simultaneous oxidation and reduction) of the superoxide radical to molecular oxygen with the formation of a less reactive ROS, hydrogen peroxide.
2. **Catalase (CAT):** The enzyme converts hydrogen peroxide to water and oxygen according to the following reaction:

$$2H_2O_2 \rightarrow 2H_2O + O_2$$

3. Glutathione peroxidase (GPx): This enzyme utilizes glutathione (GSH) as a co-factor to catalyze the conversion of hydrogen peroxide to water while yielding the oxidized form of glutathione (GSSG).

$$2GSH + H_2O_2 \rightarrow GSSG + 2H_2O$$

The most common cellular non-enzymatic antioxidants include vitamins such as vitamin C, and vitamin E. Others include thiols such as

glutathione (GSH), thioredoxin and lipoic acid, as well as natural compounds such as melatonin, produced from the pineal gland.

$$GSH + R\bullet \rightarrow GS\bullet + RH$$
$$GS\bullet + GS\bullet \rightarrow GSSG$$

GSH can be regenerated from glutathione disulfide GSSG by the action of the enzyme Glutathione reductase (GRed).

Summary

Nucleic acids are high-molecular-weight molecules that serve as a repository of genetic information in living organisms. They are polymers of nucleotide bond by 3′ and 5′ phosphodiester linkages.

DNA is the hereditary material in all animals including humans and unicellular organisms.

RNAs (mRNA, tRNA and rRNA) are produced by DNA through transcription and are used for protein synthesis.

In living celsl, nucleotides are involved in a wide range of processes including DNA and RNA synthesis, composition of many coenzymes, control of metabolic process, etc.

Ribose-5-phosphate is the first step for a series of reactions in purine nucleotide biosynthesis. Biosynthesis of purine rings is contributed by glycine, aspartate, formate and CO_2.

Other than primates, several animal species convert uric acid to more soluble forms such as allantoin and allantoic acid.

In addition to ribose-5-phosphate, precursors such as aspartate, glutamine, and CO_2 are used in the biosynthesis of pyrimidine nucleotide.

Breakdown of pyrimidines yields two amino acids: β alanine and β amino isobutyrate, which are subsequently metabolized.

Apart from its double-stranded structure, DNA also forms unusual structures such as bent DNA, triple-stranded DNA, tetra-stranded DNA, etc.

The enzyme DNA polymerase III catalyzes the synthesis of prokaryotic DNA. This enzyme has editing capabilities that correct any errors that might arise during nucleotide incorporation.

Eukaryotic replication is more complicated and involves a number of factors, including replication protein A, replication factor C, and flap endonuclease, especially on the lagging strand.
Recombination includes the exchanges of DNA in order to transfer genetic information. Movement of specific pieces of DNA (called transposons) into the genome is referred to as transposition.

Exercises

I. Essay questions

1. Describe the catabolism of purine nucleotides and the associated metabolic disorders.
2. Define programmed cell death.
3. Classify programmed cell death.
4. List the factors that initiate programmed cell death.
5. Outline the roles of programmed cell death in metabolism.
6. Describe the various tools used in genetic engineering, mandatory for developing a transgenic organism.

II. Write short notes on the following:

(a) PRPP.
(b) Synthesis of deoxyribonucleotides.
(c) Functions of nucleotides.
(d) Regulation of purine synthesis.
(e) Ribose sugar and deoxyribose sugar.
(f) hydrogen bonds in DNA.
(g) Nucleotide.
(h) Nucleoside.
(i) Nitrogenous bases.

III Multiple choice questions

1. The nitrogenous base not present in DNA structure is:
   (a) Adenine (b) Guanine (c) Cytosine
   (d) Uracil.

2. The backbone of nucleic acid structure is constructed by:
   (a) Peptide bonds (b) Glycosidic bonds (c) Phosphodiester bridges (d) All of the above.

3. The following coenzyme is a nucleotide:
   (a) FAD (b) NAD^+ (c) CoASH
   (d) All of them.

4. The nucleotide that serves as an intermediate for biosynthetic reactions is:

   (a) UDP-glucose (b) CDP-acylglycerol
   (c) S-Adenosylmethionine (d) All of the above.

5. The name of the enzyme that is associated with hyperuricemia is:
   (a) PRPP synthetase (b) HGPRT (c) Glucose-6-phosphatase (d) All of the above.

6. The nitrogen atoms in the purine ring are obtained from:
   (a) Glycine (b) Glutamine (c) Aspartate
   (d) All of the above.

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Chapter 10

VHM 201: Food Animal Production and Management

Olalekan Taiwo Jeremiah, *University of Ibadan, Ibadan,* and **Uchechukwu Chukwudi Obiekwe,** *University of Nigeria, Nsukka*

Overview

Farm animals (generally regarded as livestock) are essential to the well-being of man and therefore there is a need to understand the rudiments of processes of their production and management. This is important because the products from these animals provide one-third of the protein needed by humans. Since over 70% of emerging infectious diseases are zoonotic and some of them are transmitted by these animals, their proper management will ensure good health for humans. The concept for this course is all about animals that constitute livestock, their species, breed identification techniques, production system types, and housing.

Objectives

The objectives of this course are to:

1. identify species and breeds of livestock animals.
2. handle and restrain food animals.
3. explain animal behavior and its different components.
4. describe different livestock production systems.
5. discuss weight and age estimations in farm animals.
6. explain the effect of birth weight on losses in the livestock production system.

7. recognise the basis for disbudding and hoof trimming in animal welfare.
8. explain different techniques for livestock animal identification and restraint techniques.

Introduction to livestock husbandry

The word "livestock" can be understood as comprising of two words: "live" and "stock". It refers to domesticated animals raised and slaughtered to fulfill human appetites and economies. While livestock animals once enjoyed a close relationship with humans by providing workforce and assistance, worship and religious rituals that wanted to harmonize the earthly and the divine, and sacrificial offerings in the form of food, they have now become major sources of concern. From climate change to healthy diets, the concept of livestock has become the single most important element for the survival or collapse of agriculture. According to the Food and Agriculture Organization, any domestic or domesticated animal kept for food or utilized in the production of food is referred to as livestock, including bovine (such as buffalo and bison), ovine, porcine, caprine, equine, poultry, and bees.

Livestock production involves the raising of farm animals for food or other products. Farm animals are classified based on anatomical and physiological differences into two groups: monogastric or non-ruminants (simple-stomached animals) and ruminants (complex-stomached animals). The major example of domestic monogastric farm animals is the pig and examples of domestic ruminants are cattle, sheep, and goats. The rumen, reticulum, omasum, and abomasum are the four chambers that make up a ruminant's stomach. Due to the millions of helpful microorganisms that are present in the rumen compartment, the ruminant livestock breaks down the fibre components that are mainly contained in the forages (grasses and legumes) and roughages they consume. The abomasum compartment

is also referred to as the 'true stomach' as it functions like the simple stomach of non-ruminants.
Ruminant animals can be raised more sustainably through better land and pasture use, using existing technology and human intelligence. However, pigs are seemingly easier to handle, are major grain consumers and carriers of major diseases transmissible to man. Meat (beef from cattle, mutton from sheep/goats, and pork from pigs), milk (from ruminants), and lard (from pigs) are among the primary reasons that animals considered to be livestock are raised. Secondary considerations are the production of hides and skins, bristles, offal, manure, and wool.

Livestock species, breeds, and distribution

Livestock species refers to a class of farm animals whose members have the same main characteristics and are able to mate among themselves. Bovine species comprise a class of animals whose members are domestic cattle in different regions of the world. For example, domestic cattle in temperate regions (*Bos taurus*) and tropical regions (*Bos indicus*). Ovine species comprises a class of animals whose members are domestic sheep in different regions of the world. Also, the caprine species comprise a class of animals whose members are domestic goats in different regions of the world. Swine species comprise a class of animals whose members are pigs in different regions of the world.

A breed of livestock refers to a particular group of domestic animals with a consistent appearance (phenotype), consistent behavior, and other traits that set them apart from other members of the same species. For instance, the Texas longhorn breed of cattle in America and the Sokoto Gudali breed of cattle in Nigeria are two completely different breeds. Also, the West African Dwarf breed of goat (in southern Nigeria) is distinct from the Red Sokoto breed of goat (in

northern Nigeria) and both breeds of goat are very different from the Alpine breed of goat in Europe.

Livestock production systems: extensive, semi-intensive, intensive.

In general, the way livestock production systems are categorized reflects the individual worldviews of the individuals engaged in the care of such cattle. The United Nations Food and Agriculture Organization guidelines and feeding and stocking rates are typically used to categorize livestock production systems. Such classification is as follows in Nigeria:

1. *Extensive system of management*: Even though the term is also used for ruminants, the extensive system of livestock production, also known as the "free-range system" or "pastoralist system," primarily refers to the extensive foraging of monogastric animals. The animals are allowed to move around freely outside for at least some of the day to forage and get sunshine. Free-range is currently more of a marketing word, identifying animals raised humanely, whether kept around the farmhouse, in gated yards over gravel, in floorless temporary enclosures, or on pastures, given that the traditional free-range animal farming is being mainly supplanted by factory farms. Animals must have access to the outdoors for at least a portion of their lifespan in order to be considered free-range.

   In most parts of Nigeria, this type of system is the most common for rearing cattle and to a less extent small ruminants. The wide diversity of farming practices and management techniques reflect the various difficulties that free-range cattle must overcome. Owners of cattle in this system experience losses to herder-farmer conflicts, cattle rustling, heat stress, diseases, and malnutrition (particularly during the dry season of the year). Free-range

systems frequently employ more antibiotics and parasiticides to treat sick animals due to increased exposure to external pathogens. Some of the advantages of this system include (a) less labour, (b) the cost of production is relatively reduced, (c) little damage to the local environment and soils which are usually occasioned by overuse of pasture treatment with chemicals.

2. *Semi-intensive system of management*: This system of livestock production involves allowing the animals to roam and scavenge for food during the day and are allowed to come under a shelter in the night for protection and monitoring by the owners. In Nigeria, animals under this category of management are given attention in terms of feed and water with some level of veterinary care. Some of the advantages of this system of management include: (a) it enables quarantine of sick animals or newly acquired animals, (b) the animals have access to cultivated leguminous fodder, (c) some agropastoralist farmers developed from transhumant systems will become sedentary and begin to combine crop production with livestock production.
3. *Intensive system of management:* This system of livestock production is known as "Ranching" for ruminants and "Cage farming" for pigs. Ranching is the term for vast commercial grazing operations used to produce ruminants in developed and advanced nations. Where there is an ample amount of grazing land, these systems reign supreme with established ties to global value networks. Ranching uses high-yielding animal breeds and planting to improve grassland. For brief periods, feed is given in the form of hay, silages, coarse and small grains (as concentrates), and, to a lesser extent, industrial feeds or byproducts, particularly when pasture supply, quality, or both do not satisfy animal nutrient needs or consumption needs. Ranches deal with issues such as the deterioration of the pastures they depend on, disputes with other

industries over the use of land and resources, bad working conditions for employees, and occasionally, technical difficulties. In isolated regions, the main issues are overstocking, unsuitable pasture cultivation and utilization, as well as rangeland degradation. Substantial cow-calf production are found in the dry rangelands where no other agricultural activity can be executed effectively. It is challenging to categorize ranching goods using just one attribute due to the variety of feeding methods, pasture types, and varieties of animal characteristics, as well as pre- and post-slaughter care. In Nigeria, this system of livestock production is being advocated in the face of the extensive type of production, but not practiced fully. The agricultural method known as the "farm settlement system" that was implemented by the administrations of the former southwestern region of Nigeria serves as a blueprint for ranching.

4. *Other types of livestock production systems are:*
   - **(a)** Landless livestock production: This is a system for raising livestock without reliance on land, in which under 10 percent of the dry food used by the animals is grown on a farm, and in which the typical yearly stocking rate is higher than ten animal units per hectare of agricultural land.
   - **(b)** Grassland-based system: Is a system based on pastures when over 10% of the dry food used by the animals comes from farms and where the yearly average population density is under ten animal units per hectare of arable land.
   - **(c)** Mixed-farming system: Is a system that includes both livestock and non-livestock farming, where more than 10% of the dry matter given to animals originates from crop by-products or straw or greater than 10% of the total value of production. There are two different types of mixed farming systems: (i) a subset of rain-fed blended systems of farming,

where over ninety percent of the value of non-livestock farm output comes from rain-fed land use; and (ii) a portion of irrigated blended farming systems, where over ten percent of the value of non-livestock farm production comes from irrigated land use.

(d) Silvopastoral systems, which integrate the production of tree crops with grazing pastures or fodder. Agro-silvopastoral systems incorporate crops, multipurpose hedgerows, woodlots, or fodder trees with domestic livestock. Multiple types exist within these broad categories in terms of their functional traits such as the parts of trees and shrubs, productive uses such as crops, food, fodder, and fiber, and beneficial uses like windbreaks and soil conservation. High tree and shrub densities are planted in grazing land, cut-and-carry processes are used to provide livestock with shrubs and trees that were particularly planted in areas that were formerly utilized for other kinds of farming, and rapidly growing trees and shrubs are used for windshields and fences. It is possible to manage silvopastoral systems intensively or broadly.

Estimation of live weight and age

In order to determine the carcass weight and dietary level for cattle, a correct measurement of the animal's weight is essential (which also directly influences medicine dosing). Although there are many methods that can be employed in the weight determination of livestock, the use of a weighing scale is the golden rule. However, in rural settings in Nigeria, ruminants and pigs are rarely weighed because of the high cost of weighing instruments and expensive maintenance costs associated with the difficulty in transporting them to farms. Therefore, visual

observations/appraisals (with their limitations and inaccuracies) are often brought to play while estimating the weights of such livestock. The use of weight bands (with calibrations) is also advocated on our farms. Directly behind the pommel of the shoulder, along the foreribs, pursuant to the body behind the elbow, and then all the way surrounding the point behind the shoulder blade are wrapped with the weight band. On top of the goat's vertebral column, the weight band's ends are overlapping. The final step is to read out the determined weight measurement on the weight band. A different method is known as body linear measuring, in which an animal's size and weight can be estimated using linear dimensions. The height at withers, heart girth (HG), chest depth, body length, fore cannon bone, rump height, the distance between eyes, ear length, ear width, paunch girth, and tail length are the most utilized body linear measurements. The dimension of the cannon bone and the heart's circumference is not significantly impacted by the animal's position. The HG or chest circumference techniques are more options. A measurement of the chest's circumference taken just behind the front legs and withers is called heart girth. The distance should be measured to the closest 0.5 cm. Though it does vary slightly with extremes in posture and possibly as the animal inhales and exhales, HG is a highly reproducible measurement. As there is a significant relationship between chest circumference and body weight within breeds, sexes and ages of stock, it serves as the foundation for the numerous weight tapes that are available for estimating animal weight. Mature animals provide strong HG-live body weight connections. When measuring HG in small ruminants with enormous amounts of hair, be sure to tightly pack the hair.

Knowledge of the age of the individual animal forms an essential part of anamnesis in aid of proper clinical diagnosis. In chemotherapy as well, the choice of and dosage of certain medicaments is influenced by the age of the animal patient. In Nigeria, most livestock owners do not

keep written records of the births of their animals. Age estimation is therefore the major method often employed. The use of rostral dentition is one of the most acceptable methods of age estimation in animals, in which animals are examined once or regularly during the period of teeth development. Using this technique, the eruption and presence of milk and permanent teeth will form the basis of the estimated age of the animal being examined.

Emphasis on birth weight, litter size, weaning age/weight and growth rate

The impact of newborn weight on weaning losses, weight at slaughter, and carcass condition are frequently prioritized in most livestock farming operations. As a result, reports on the impact of the newborn's weight or growth rate on the onset of puberty or on the life expectancy of female farm animals exist. Genetic selection for larger litter quantities has reduced birth weight and increased within-litter variation in livestock animal output. These elements may increase pre-weaning mortality, which will have an immediate impact on the number of young animals available for breeding. Low birth weight puts farm animals at risk for pre-weaning mortality, illnesses, stillbirth, and has a negative impact on their ability to grow after birth. Since young female animals account for a disproportionately high percentage of females in reproduction, their reproductive success has a significant positive impact on the financial success of livestock farms. Growth rate and puberty age are frequently linked to female livestock animals' overall output. Early breeding of young female animals with increased growth rates is recommended since it gives the chance to choose females with traits that lengthen their lifespan and boost the economic value of such animals.

Disbudding, dry hoof trimming

Globally, it is well known that farm animals experience pain in one way or the other. The pain experienced by food animals may be a result of

animal management procedures such as castration, disbudding/dehorning, hoof trimming, and tail docking or other medical conditions including lameness and dystocia. Many of these procedures are performed on farms without the use of analgesics or anesthetics for pain management. It is crucial to treat farm animals humanely, and they should be raised with the intention of giving consumers a satisfying, healthy, and safe eating experience. Therefore, proper castration, dehorning, dry hoof trimming, and docking techniques can have an advantageous effect on animal health, carcass quality, and consumer satisfaction. To reduce pain and distress, due diligence should be ascribed when implementing any of these management procedures.

Disbudding/Dehorning: Animals frequently sustain bruising and other wounds from horns. Horns can also endanger both people and machinery. Depending on the age of the animal and the stage of horn growth, the method of disbudding/dehorning involves removing an animal's horn buds or horns. For small ruminants, disbudding/dehorning should take place between 7 and 10 days of age, and for cattle, it should happen before 3 months. It should be noted that using polled breeding stock is possibly the easiest and most efficient way to dehorn animals. Caustic paste, an electric horn removal iron, or a mechanical dehorner (spoons, tubes, or scoop-type dehorners - all for use on calves exclusively) can be used to complete this procedure. It has become standard procedure to apply the caustic paste on the horn bud. To avoid getting the paste on oneself or in the animal's eyes, due diligence must be exercised. Electric dehorning irons are used to "kill" the horn by burning the horn bud along with surrounding tissue. Mechanical techniques are applicable to cattle. The wound should be kept as spick-and-span as possible. During this procedure, bleeding should be avoided.

Dry hoof trimming: Hoof clipping is essential for keeping hoofed animals from becoming lame. It is very important to prevent lameness because

of animal welfare and the economic losses often incurred by animal owners. Hoof trimming therefore renders our farm animals less susceptible to structural lameness and bacteria-related lameness. The ability to bear weight occurs on the outer horny area of the typical foot in the majority of common agricultural animals. There is resultant lameness once weight bearing shifts from the normal position, hence the need for a flat surface for weight bearing which hoof trimming achieves. It is often advisable to perform hoof trimming twice a year if there are no infectious diseases on our farm. Hoof trimming in sheep is carried out when the animal is on its rump while goats, cattle, and pigs should be allowed to stand during the procedure. The tools often employed during hoof trimming procedures are hoof knives, grinding wheels, and hoof nippers.

Tagging and branding

Identifying livestock is essential for contemporary agriculture and successful farm administration. Currently, this phenomenon is viewed as a crucial step in managing the safety policy for animals and the ethical production of food animals. Animal identification, therefore, is the basis for keeping accurate production records of the animals. There are several methods of animal identification for profitable livestock production.

Tagging: One of the many techniques of identification that have been used throughout history is the tagging of animals. Here, plastic ear tags with numbers are inserted within the second and third cartilage ribs of the animal's ear using ear tag pliers (or ear tag applicators), making the tags simple to see from both the front and the back of the animal for recognition. In Nigeria, there are two types of ear tags available for use in cattle: (i) the European type and (ii) the American type (Figure 1) and respective applicators (Figure 2 and Figure 3). In the swine industry, ear tags are also used but mostly ear notching is the singular and most popular method of identification.

Branding: One of the oldest methods for recognizing animals, it has roots in both ancient Africa and the Bible. In this technique, irons are heated to create brands using either fire or electricity. After being red-heated, brands are put to the animal's skin, where the hair vesicle development cell is decimated to produce the permanent marking. Freeze branding is a type of branding where the branding irons are frozen. This kind of branding involves freezing alcohol using dry ice or liquid nitrogen. When the brand is placed to an animal's skin, the frisson iron will only damage the dying hair cells while sparing the new hair cells. White or colorless hair will then mature and have a lasting brand grade after this.

Figure 4: European (Red) and American (Green) pre-numbered ear tags for cattle

Figure 2: European Ear Tag Applicator

Figure 3: American Ear Tag Applicator

Restraint techniques and handling

For safe and efficient animal handling, a detailed understanding of animal behavior norms and each species' reactions is necessary. The first piece of advice is to always use the least restrictive technique possible while handling any kind of animal. This does not imply that we relinquish control of the animal; rather, it simply means that we exercise the least amount of restraint while remaining in charge of the circumstance. There are no restrictive guidelines as to which approach is most effective in which circumstance because every animal and every

circumstance is unique. We must be aware that overbearing restraint will make our animals fearful.

Take a minute before attempting to restrain an animal to give it a chance to get accustomed to you by taking the following actions: (i) stoop down until you are at their eye level, (ii) avoid sitting on the ground because you will not be able to get up or defend yourself in case of emergency, (iii) avoid making direct eye contact with the animal but keep a safe visual distance between you and it, (iv) speak in calming tones rather than in a strong-pitched, eager voice, (v) try patting the ground or your leg to attract the animal's attention. For ruminants, a major restraint technique is called flanking. This method is carried out by reaching over the animal's flank and grasping the nearest hind leg to cast the animal down. Another type is jaw restraint (especially for small ruminants). For the pigs, one can vertically hold the legs of the animal with the head up and belly out and this constitutes an additional restraint between the knees of the holder. There are several restraint tools that can be employed while handling farm animals which include halters, stanchions (comprising milking parlor and treatment pen), squeeze/cattle chutes (comprising a close head gate, close tailgate, and close side), lane chute (for crowd multiple cattle), and cast ropes. Other tools are a hurdle board, head gate crate, and nose snare (for pigs).

Animal transportation

Animals are transported both domestically and globally for consumption (slaughtering), health-wise, agricultural or animal shows, marketing, relocation, and reproduction (breeding). To guarantee the well-being of the animals, there are rules and legislation governing animal transportation. The rules and regulations involve all the practices and precautions taken to ensure appropriate and correct transportation of animals during short and long-distance movement. Generally, animals can be transported in a car, lorry, trailer or articulated vehicle, train, or airplane, however, some people transport animals unconventionally via

motor bicycles, bicycles, hand push trucks, and physical carrying of the animals. Animal transportation equipment must be built, maintained, and operated in a way that prevents harm and suffering to the animals being carried in it. Animals transported by land, air, sea, and rail are subject to regulations. Various animals have different requirements, some of which include:
(a) to lessen stress and suffering, (b) to ensure the protection of the animals and shield them from inclement weather, scorching heat, and climatic changes, (c) keep the animals from escaping or falling out and be able to handle the pressures of movement, (d) enable cleaning and disinfection.
Bars should be present during loading and unloading to stop animals from falling. Additionally, confirm that the quantity and quality of the air are appropriate for the kind of animal being carried. Give the animals exposure so they can be looked after and evaluated. Make sure the flooring is non-slip. Give a floor covering that stops urine or faeces from leaking. Provide a means of lighting that is adequate for animal care and inspection during transportation as well as during loading and unloading.

Nomadism, pasture management and animal housing

In order to adapt to climate change, pastoralists maintain rangelands using traditional methods that are defined by migration. Animals are kept on farmland or open land surfaces by farmers who sedentarily use the land for agricultural cultivation. When conditions allow, ranchers may plant grains and hay to feed livestock, but rangers typically employ broad land expanses for grazing.

For thousands of years, pastoralists have taken care of herds of domesticated animals, offering a variety of services to subsistence farmers. In accordance with the ecosystem, there are several types of pastoralism, such as transhumance, seminomadic mixed herding

farming, and nomadic due of irregular pasture. Typically, pastoralism flourishes on rangelands that are unsuitable for intensive farming and have relatively poor biological productivity. Traditional knowledge, time-tested practices based on inference and ground trotting (as is done in many parts of Southern Nigeria with the Fulani herdsmen), and a capacity to adapt to changing conditions are what set pastoral systems apart. While some pastoral systems (like those using additional feed crops) have incorporated aspects of intensification, others continue to be characterized by low input/multiple produce systems (transport, manure, milk, fiber, leather, and meat) that are especially suited to regional climate variations. In Nigeria, over 80% of the national herd is owned by pastoralists, who depend on natural pastures for their animals. Most cattle are concentrated in the Northeastern and Northwestern parts of Nigeria implying the names of some breeds of cattle such as Adamawa Gudali and Sokoto Gudali cattle.

A short rainy season of about 3-4 months often occurs in the northern parts (the Sudan vegetation zones) of Nigeria. Hence, there is an inadequacy of pasture during most periods of the year in that part of the country. At the end of the season of rainfall, pastoralists trek with their cattle to the densely populated southern regions with lush vegetation, precisely in the month of November. This is called pastoralism with massive transhumance. The animals are again moved northwards at the beginning of the next rainy season (to avoid the tsetse fly challenge which occurs annually in the south).

Some of the advantages of nomadism include: (a) it helps to prevent over-grazing, particularly in the case of transhumance, (b) it removes the necessity of constructing permanent structures with high cost, (c) it requires less capital input and labour, (d) it encourages communal harmony between the pastoralists and the people in the local settlements as is the case in the northern parts of Oyo State, Nigeria where some indigenes are said to be married to the Fulanis. However,

some of the disadvantages of nomadism include: (a) exposure of the herders and their stock to security challenges such as cattle rustling, (b) animals and their owners are prone to attack by wild animals and dangerous reptiles, (c) instability (social, politically, educationally, and emotionally) is the all-mark index for the family members of herders.

For efficient livestock production and management, particularly in the intensive and semi-intensive systems, prompt attention should be paid to the housing needs of the animals. Housing is provided for the purpose of sheltering the animals in the night and protecting them from rain (cold) and heat stress from the sun. The house also provides security for the animals and helps the farmer to monitor the animals more closely. Animal houses can vary in type depending on the management system being practiced and the prevailing economic situation of the farmer. The type of houses being used by farmers in Nigeria ranges from mud houses with thatched roofs to corrugated iron walled buildings and blockhouses.

Some desirable features of a good housing facility for livestock production are: (a) it should be located on well-drained soil and on an elevated area to avoid water logging and flooding, (b) it should be well-ventilated to avoid dampness, (c) its floor should be cemented or made of rammed earth to facilitate cleaning while the walls should be free from cracks and crevices, (d) the housing facility should be divided into pens to serve various production purposes - fattening, breeding, calving/lambing, farrowing, and nursing, (e) there should be separate pens for each sex of adult animals and for quarantine purposes, (f) appropriate floor space requirements for each category of livestock should be adhered to depending on the species of the livestock animals.

Summary

The livestock production system in Nigeria focuses mainly on farm animals such as cattle, sheep, goats, and pigs. These animals have their different breeds spread across the nation with varying systems of

management. The identification of these animals is of utmost importance for proper record-keeping and management using different techniques. The weight and age estimations are central to the well-being of these farm animals for efficient drug therapy and veterinary care. A good housing system for these animals will help them produce optimally.

Exercise

1. What are farm animals? Give two examples.
2. Give an example of monogastric animals and an example of ruminants.
3. Mention two breeds of cattle in Nigeria.
4. What are the three systems of management of livestock in Nigeria?
5. Mention a technique for estimating the age of a ruminant.
6. Mention an advantage of dehorning in ruminants.
7. What is branding in livestock?
8. Mention two ways by which livestock animals can be transported.

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Chapter 11
VHM 202: Companion and Wild Animal Management

Chapter 11A
Management of Companion Animals

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Overview

The knowledge of companion animal management is vital to the administration of routine and specialized veterinary care for animals. This chapter briefly summarizes important principles and practices related to companion animal management. A brief introduction to the taxonomy and breeds of some companion animals is followed with instructions on the basic care of some companion animals including grooming and dental care which was followed by a discussion on risks involved in the management and care of the animals. Useful feeding and training tips are also highlighted. A section on restraint techniques is supported with practical demonstrations to increase student participation. Animal behaviour is briefly introduced, and housing tips are given. The chapter concludes with a brief mention of modern techniques applied in the routine management and health of companion animals.

Objectives

The objectives of this course are to:

1. identify different breeds of dogs and cats and explain their uses;
2. perform basic restraint techniques in small animals;

3. perform basic grooming of dogs; and
4. describe modern technologies in the management and care of companion animals.

Introduction

Companion animals are domestic-bred or domesticated animal species whose emotional, physical, social and behavioral needs can be eagerly met as companions at home, or in close day-to-day association or connection with humans (ASPCA, 2018).

The dog is probably the first animal to be domesticated by humans and various scientific reports put this at between 12,000- 23,000 years ago. Modern dogs probably descended from the wolf. It has been postulated that while these animals roamed in packs and found it easy to find discarded food from man rather than hunting for it, humans also found that they could depend on dogs to alert them of danger. Modern dogs evolved from selective breeding for specific purposes.

The domestication of cats took place much later (about 3500 years ago) probably because of its independent, solitary nature. Cats have been greatly valued by farmers, ranchers and homeowners because of their use in controlling rats and mice.

Dogs and cats are believed to be descendants of the same carnivorous, tree-climbing mammal, Miacis.

Table 1: Taxonomy of Dogs and Cats

Dog	**Cat**
Kingdom – Animalia Phylum - Chordata Class - Mammalia Order - Carnivora Family - Canidae Genus - *Canis* Species - *C. familiaris*	Kingdom – Animalia Phylum - Chordata Class - Mammalia Order - Carnivora Family - Felidae Genus - *Felis* Species - *F. catus*

Breeds of Dogs and Cats

The word 'breed' is defined as a group of related animals which are genotypically and phenotypically sufficiently similar to produce physically similar offspring when they are mated with each other. However, in most countries, breeds are managed by a breed association that defines the standard for physical appearance and maintains a register of the animals that are members of the breed.

Dog breeds come in a very wide variety of sizes. Generally, dog breeds are grouped into Toy breeds, Working breeds, Sporting breeds, Terriers, Hounds, etc. Irrespective of breed, all dogs are *Canis familiaris*

Common breeds of dogs

Nigerian Indigenous Dogs (NIDs) are erroneously called mongrel (an animal of uncertain breed mix) due to the lack of standardization of the breed. They are commonly used by hunters and are quite popular in rural areas and suburbs. The NID is gaining popularity because of its low purchase and maintenance cost as well as innate resistance to many common canine diseases.

There are several imported breeds of dogs, many of which have become domiciled in the country. Some of the popular ones are: German shepherd dog (Alsatian), Boerboel, Rottweiler, Caucasian, Lhasa Apso, Samoyed, Pitbull, American Eskimo, Dobermann and Cane Corso.

Uses of dogs

Dogs are mostly kept for security purposes in Nigeria. Many keep them as pets and there is a growing number of commercial dog breeders in Nigeria. Security agencies such as the Nigerian Army, Police, Customs, and Correctional services all have canine units. The dogs in these units perform specialized duties ranging from detecting illicit drugs at the ports to sniffing out land mines on the battlefield. Elsewhere, dogs serve disabled people and even babysit. They also play a great role in biomedical research where they are often used to study human diseases.

Breeds of cats

In Nigeria, cats are not as widely kept as dogs. While a handful of people keep cats as pets, many others use them for rodent control. There is now a growing population of pet cat owners in the country. Common breeds of cats in Nigeria are the domestic short-haired (not a breed *stricto sensu*), Persian, Siamese, and Scottish fold cats.

Grooming of Dogs and Cats

Apart from maintaining a good aesthetic appearance in pets, regular grooming helps to keep the coat healthy. Old and damaged hair fibres are removed in the process, and this helps to keep the coat healthy. Grooming also helps to check for the presence of ectoparasites such as fleas, flea dirt, and skin problems which may be hidden by the hair coat. Cats practice a lot of self-grooming hence, grooming also serves the very important role of preventing the formation of hairballs which can lead to intestinal foreign body obstruction.

Different breeds of dogs and cats have different types of coats hence, it is extremely difficult to generalize on details of the grooming procedure. However, a schedule of grooming that has been found to be good for a particular pet should be adhered to regularly and conscientiously rather than sporadically. Cat breeds that have lung fur such as the Himalayans and the Persians require more frequent grooming than the short-haired ones in order to prevent matting of the fur.

Grooming has four components:

I) Bathing

II) Brushing

III) Nail trimming/paw care

IV) Haircuts

I) Bathing. Bathing helps to remove dirt and debris from the coat of the dog and thereby keeps the skin healthy. Bathing should

however not be done too frequently because it can lead to irritation of the skin and predispose dogs to dermatitis. A frequency of once a month or once in three months is sufficient in dogs. Water used for bathing dogs should be warm. It should not be warmer than the dog's skin. Most cats resent water and they do not need to be bathed frequently. Cats practice self-grooming and will only need a bath when they are very dirty or filthy. Like dogs, cats also should be bathed with warm (not hot) water.

II) **Brushing.** Regular brushing aids in the removal of dead hair from the pet's coat and stimulates blood circulation on the skin. Brushing prevents matting of the hair and skin irritation while also reducing the shedding of hair around the house. The frequency of brushing depends on the length of the hair with pets having long hair requiring more frequent brushing than those with short hair.

III) **Nail/claw trimming.** Pet nails when left untrimmed can cause pain and lead to irreversible damage. Long nails also create the potential for the development of splayed foot, deformed paws, injury to tendons, arthritis and pain. In addition to these, overgrown nails in house-dwelling pets can lead to inadvertent destruction of furniture by these pets. Dogs that are active and healthy dogs do not need frequent nail clipping as the nails will wear naturally with everyday use to remain just clear of, or just touching, the ground when standing normally. An exception may be the dew nail, which can grow into the nail bed if left unchecked. The nail has two parts: the quick, which is a soft cuticle that contains blood vessels and nerves which run through the nail and the hard outer material known as the shell. Trimming the nail too deeply can lead to bleeding and pain and care should be taken to avoid trimming beyond the nail curve. In dogs with light-coloured nails, the quick can be easily visualized. This may be difficult in dogs with dark nails but a look at the underside of the nails might show a groove which separates the hard nail from the soft cuticle. When nails are trimmed regularly, the quick recedes from the end,

creating a short quick. In cats, the tip sharp claws are snipped off and no more.

IV) **Haircuts.** Dogs with low-maintenance coats such as the Nigerian indigenous dogs have no need for haircuts. Long-haired dogs require more frequent haircuts to maintain a healthy coat. In cats, haircuts are typically not recommended except in some long-haired breeds whose fur have become tangled and matted. When the mats exist for long, there is an increased likelihood of the underlying skin getting inflamed and irritated leading to great discomfort. A lion cut shave is a style of grooming in which most of the hair is removed using specialized clippers on the body of the cat but leaves the hair on a few small areas. In the typical lion cut, hair will be left on the face and head, lower half of all four paws, and the tip of the tail. The lion cut is most useful for long-haired cats. The lion cut is not indicated in older cats as their skin becomes thinner, thereby making it more susceptible to nicks and cuts.

Dental care in pets

Dogs and cats are predisposed to a number of dental diseases if their oral health is not adequately maintained. Prevention of most of the oral diseases that pets are susceptible to involves the frequent removal of dental plaque which can form on their teeth when not kept clean. The most efficient way to remove plaque and tartar is daily brushing of teeth. Brushing with the appropriate toothpaste is advised. It is very important to note that human toothpastes are not suitable for use in pets.

Modern Technologies in the Management and Health of Companion Animals

I. *Breeding and Genetics*

Modern technologies can be used in animal husbandry where genetic worth of breeding animal species may not attain the anticipated

performance without utilizing cutting-edge or modern technology. Different breeds in animal husbandry system have improved immensely using gene and breeding technology. Also, genomic selection offers more potential for increased rate of genetic improvement particularly within the livestock sector. In addition to new reproductive technologies, there is plausibility of making use of stored germplasm to aid conservation measures especially for genetic diversity maintenance in species that are threatened (Holt and Pickard, 1999; Omonona *et al.*, 2018). With advances in genomic sequencing, researchers have the capability to better comprehend the genetic makeup of animals as well as develop more targeted and effective diets. This can be particularly useful in companion animals with specific dietary needs, such as those with food allergies or digestive disorders. By developing customized diets based on an animal's genetic make-up, veterinarians are able to optimize their health and well-being. Gene therapy is another emerging field or technique, which involves modifying the genes of an animal to treat a genetic disorder or disease. This technique has already been used successfully in companion animals to treat a range of conditions and holds great promise for the future.

II. *Computer and Internet Usage*

Novel technology in the form of biotechnology, computers, scientific innovations with regards to ruminant genetics and nutrition affords the foundation for hastened advancement in the production of milk for dairy farmers who espouse these technologies. Computer utilization for farm management particularly in the dairy sector began in the 1990s in several developing countries of the world. Another major advancement is also in digital diagnostics which allows for more accurate and detailed imaging of internal structures. Radiography, ultrasonography, and magnetic resonance imaging (MRI) are now commonly used to help diagnose and treat a range of diseases and injuries in animals. Digital imaging has significantly improved the accuracy of diagnoses, allowing better target treatments and ensuring the best possible outcomes.

III. *Electronic Identification*

Electronic identification system kicked off in the early 1970s. However, according to Rossing (1999), current regulations and laws deal with the

readable markings (visual) that are positioned on the animal. There are several animal identification technologies that are privy to livestock farmers. For instance, Radio frequency identification (RFID) is being utilized for cattle identification. These devices possess an electronic number which is exclusive to an individual animal and which links the animal to a database (Artman, 1999). As stated by Iddings and Apps (1990), injectable transponders, electronic ear tags, as well as boluses with a transponder within the reticulum are the newest technology for identification of animals. Several forms of RFID tags (as listed above) are being made use of as intravenous placement for identification of animals, and they function using a radio frequency for sending data to base computer for evaluation.

Risks Involved in the Management and Care of Companion Animals

There are several risks involved in the management and care of companion animals. These can be grouped into physical, chemical and biological hazards.

I. **Physical hazards** include animal kicks, bites, scratches and trampling. Physical hazards can be avoided by proper training, restraint, and habituation of the animals. The manner of approach to the animals also matters. For example, it is advisable not to approach a horse from its behind or enter a cattle enclosure wearing a red outfit.

II. **Biological hazards** include diseases, parasites or allergens that can be acquired from companion animals. Diseases that can be acquired from animals are called zoonoses and they include Rabies, Salmonellosis, Leptospirosis and Q-fever. Some people may have allergies from animal dander or urine. Biological hazards can be prevented by proper use of personal protective equipment (PPE) such as coveralls, gloves, face masks and gloves. Vaccination of susceptible animals and occupationally exposed personnel against zoonosis such as rabies is also important.

III. **Chemical hazards** may be in the form of chemical burns, skin/eye irritation which may occur while handling drugs or chemicals for animal or environmental use, concentrated cleaning agents or cancer from being exposed to carcinogens. For example, formalin, which is often used to fumigate animal premises, is a carcinogen. Chemical hazards can be avoided by the proper use of PPE.

Animal handlers and veterinarians may also be exposed to other hazards such as injury from equipment or instruments (e.g., needle prick), radiation exposure during certain procedures (e.g. X-ray), etc.

Feeding

Dogs may be fed commercially prepared dog food or home-cooked food. The minimum protein requirement in dogs is 21% crude protein. Puppies are usually fed about 3-4 times a day as their digestive systems are not yet developed to handle a single, large quantity of food. Cats on the other hand are true carnivores and therefore require almost twice the amount of protein as that contained in the diet of dogs. This protein is best obtained from animal products such as meat, meat by-products, fish, milk and egg. The fat content of the cat's food should constitute about 10%. Fat is a good source of calories and essential fatty acids. Cats can be fed commercially available cat foods but if fresh food is to be fed, it is of utmost importance to provide a variety as strictly feeding meat, chicken, fish, and other muscle meats can predispose the cat to a number of diseases such as poor eyesight and stunted growth due to the deficiency of calcium and Vitamin A.

In both dogs and cats, the bone in meat should be removed to prevent lodgment of bone in the digestive system. Excessive feeding of liver can lead to hypervitaminosis A. Feeding raw egg white for prolonged periods can lead to biotin deficiency. Raw egg white contains avidin which tightly binds biotin, thus making it unavailable for intestinal absorption.

Feeding/foster care of orphaned animals

The role of a dam is very vital for the nutritional support of neonates and infants. Sometimes, neonates need to be hand-reared due to problems such as rejection by the dam, death, or poor mothering ability of the dam. Supplemental feeding may be necessary if the dam is not producing enough milk, or the litter is large. In some species, the neonate can be reared by another nursing animal although rejection and infanticide are of concern.

It is advisable to ensure that neonates receive colostrum from the dam (if possible) before being taken for foster care or hand raised. Colostrum contains antibodies that protect the neonate from diseases to which the dam is immune. Artificial colostrum is commercially available but scarce. There is home-made artificial colostrum, details of which are available elsewhere. Species-specific commercial milk replacers are the ideal meal for neonates within the first three weeks of life. Common brands of milk replacers for puppies are Esbilac® and PetLaC®. Milk meant for adult humans should not be used for infant animals younger than three weeks. It might cause diarrhea and poor weight gain. If species-specific formula is not available, human infant formula should be used. During the first week of life, it is advisable to feed pups every 2-3 hours. This is usually very stressful for pet owners. Hygiene of the feeder is essential.

Puppies should be able to lap milk from a shallow tray as from 3-4 weeks of age. At this time, they can be gradually weaned by offering a mixture of milk and pap/custard. A puppy-weaning formula that has been used with huge success is provided below:
Pap/custard with sugar is properly cooked and made watery. An egg is broken into the pap/custard just immediately the heat is turned off. Note that food for puppies should be served at the right temperature (35-39°C).

Major problems with neonates are *hypothermia*, *dehydration*, *starvation* and *aspiration*. It should be ensured that pups are kept in a clean and

warm environment (29.5-32°C /55-65% humidity). Cold pups will cuddle on each other, and starving pups will cry a lot. For animals with strong suckling reflex, use pin-holed nipple feeder to prevent aspiration which can lead to life-threatening pneumonia. The use of syringe is not advisable but in emergency situations, it should be used with caution to prevent aspiration. As from six weeks of age, puppies can be started on commercial or homemade puppy food.

Basic Training of Puppies and Adult Dogs

There are many types, methods and classifications of dog training. However, every dog should undergo *toilet training*, *socialization training*, *leash training*, and *confinement training*. Depending on the purpose of the dog, *obedience/command training*, *protection/security training*, and/or *agility training* may be added. The ease of training a dog would depend on its age, pedigree and breed. The American Veterinary Society of Animal Behaviour (www.avsab.org) advocates that dog training should start between 7 and 12 weeks of age. However, toilet training becomes more effective between 12 and 16 weeks of age when the puppy has gained better control of its bladder and anal sphincter. Certain breeds of dogs have been proven to be amenable to certain types of training and a dog of good pedigree is likely to learn fast.

Positive reinforcement in which good behavior is rewarded with *play*, *praise*, *petting* and/or *treats* is recommended. Punishment-based training (e.g., E-collar) or dominance methods (the alpha dog technique) are of animal welfare concern and often result in aggressive behaviours in the long run.

Toilet training of dogs: This is aimed at designating a place and routine for the dog to defaecate or urinate. It is usually not convenient for the dog and its trainer to modify a dog's urination schedule because it is advisable to give water *ad libitum* and hence urination frequency often outweighs defecation frequency.

Things to note while toilet training your dog include:

1. Choose the type or combination of rewards.
2. Choose you disapproval signal and stick to it. A loud clap or word (e.g. Stop!, No!, or Bad!) should suffice. Your voice should not be too harsh.
3. Designate a fixed spot for defaecation (potty area) and stick to it in order not to confuse the dog.
4. Have a fixed feeding schedule. Most dogs defaecate 5-30 mins after feeding. Therefore, you should take your dog to the potty area five minutes after feeding.
5. Plan for how the dog would defaecate when you are not around. For your convenience, you may schedule the dog's toilet schedule to: at daybreak, after breakfast, after dinner, and before bedtime.
6. Learn your dog's pre-toilet cues. Many dogs sniff around, pace around, whine or sit close to the door when pressed.
7. When accidents happen (i.e., dog defaecates at wrong spot), do not scold the dog or rub the evidence on its nose. Just take the dog to the potty area and clear the evidence. However, if you catch the dog in the act, give your disapproval signal and then take the dog to the potty area. Reward the dog after it completes the act at the right spot.
8. It takes patience to toilet-train a dog (7 days to 6 months!)

Animal Behaviour/Ethology

Ethology is the scientific study of animal behavior, particularly in the natural state. There are two major types of behaviors which are *unlearned (innate)* and *learned (acquired)*. Innate behavior is also called *instinctive* behavior. There are three types of learned behaviours which are *imprinting*, *conditioning* and *imitation*.

Instinct is a complex of unlearned responses characteristic of a species or breed. Examples include herding behaviours in certain breeds of dogs, building of nests, animal courtship behavior, and suckling reflexes of neonates.

Imprinting is a kind of learning in the very young based mainly on maternal attachment and acquisition of basic behavior patterns. For example, ducklings following the first moving animal they see.
Conditioning is behavior modification in animals. *Classical conditioning* (Pavlovian conditioning) is a form of learning in which a response is elicited by a neutral stimulus which previously had been repeatedly presented in conjunction with a positive stimulus while *Operant conditioning* uses rewards and/or punishments to modify behavior. Operant conditioning may be achieved by, for example, giving treats to a dog each time it performs a particular task (positive reinforcement) or scolding a dog when it exhibits a particular behaviour (negative reinforcement).
Imitation is behavior acquired by observation. For example, parrots imitate words spoken by people. A dog was observed to be imitation its limping owner.

Other terms to know:
Zoochosis is stereotypical behavior of animals, especially wild animals in captivity. For example, perimeter pacing of jackals.
Vices are habitual abnormal behaviours of a destructive kind (e.g., pica, dogs tearing furniture, tail-biting in pigs and vent picking in chickens).
Habituation is the gradual adaptation to a stimulus or to the environment. A monkey can be habituated to present its hand for blood sample collection using positive reinforcement.
Aggression describes behavior that is destructive and intended to be injurious. There are various types of aggression in animals, namely: *fear-induced, pain-induced, food-related, dominance, maternal, territorial, predatory, protective/possessive, redirected,* and *play aggression*.

Disease (e.g., rabies) or certain physiological states (nesting behavior during pregnancy or protrusion of dulaa in male camels in rut) can alter the usual behavior of an animal. For example, hunger may lead to infanticide among carnivores.

Housing of Dogs

Kennels must provide ample opportunity for the residents to thrive. Dogs must be able to stand upright, stretch fully across the sides of the kennel and walk around the kennel space. It must be appropriately sized to have feed, water and possibly toys. Kennels can be constructed out of wood, plastic, metal, stainless aluminium plates, concrete block or a combination of the aforementioned materials. Kennels should be above all-escape proof; the doors must be built in such a way that the dogs cannot push or pry it open. The temperament, species and size of the dog will also determine the space allocated. The kennel space is not a permanent quarter for the dog; room should be made for an exercise yard or run.

Basic tips about keeping kennels

1. Tiled or well-plastered walls are recommended for built up kennels.
2. The kennel floor must be set to drain water off the slope.
3. When the kennel is to be washed, the animals must be brought outside.
4. Pack out all inanimate objects (feeding bowls, waterers and toys).
5. Sweep/pack solid wastes (excreta, fur) from the floor before rinsing the floor with water.
6. Use antiseptic soap/mild hypochlorite solution to wash the floor and walls, rinse with water, sweep away water.
7. Allow the floor and walls to dry before readmitting the kennel residents.
8. The run-off water must not pass where the dogs could have access to lapping it off; these could be harmful to the animals.

Note: In case of cleaning because of parasitic infestation, there are acaricides for this purpose.

Restraint Techniques and Animal Handling (Dogs and Cats)

There are three types of restraints for dogs and cats: physical, chemical, and psychological restraint.

Physical restraint: this is the application manual or mechanical means to limit the amount of mobility of an animal. Common tools used for physical restraint of dogs include leash, dog muzzle, and tape muzzle. Some situations may warrant the use of a dog catcher/noose pole or net. Hand restraint is also used either alone or with restraint tools to handle dogs. Cat muzzles are commercially available but dog muzzles for small-sized brachycephalic breeds can be adapted for cats. The cone from plastic water bottles can be improvised to serve as cat muzzle. If cat boots are not available, a cloth or towel can be used for full-body restraint of cats to prevent scratches.

Chemical restraint: involves the use of drugs to limit the movement of the animal. There are three groups of drugs that are used to retrain dogs and cats. They include *sedatives*, *tranquilizers* or *anaesthetics*.

Psychological restraint: involves the use of sensory stimulation to modify an animal's behavior in order to achieve control e.g., voice, gentle stroking, and diversionary restraint.

Practical demonstrations

1. Application of standard muzzle on a dog.
2. Application of tape muzzle on a dog.
3. Lifting a dog onto an examination table.
4. Holding a dog in a standing position.
5. Holding a dog on sternal recumbency.
6. Holding a dog on lateral recumbency.
7. Full-body restraint of a cat using cloth/towel.
8. Making a cat muzzle using plastic bottles and rubber bands.

Application of Modern Techniques in Routine Management and Health of Companion Animals

Recent advances in technology have provided animal owners and caregivers a myriad of convenient and efficient ways of managing animals and monitoring their health status. For example, podometers attached to the legs of animals can monitor their movement remotely.

Electronic identification systems, animal tracker chips and sensors are becoming very common. Milking automation and milk monitor sensors are now used to check for milk quality and detect diseases such as mastitis remotely. There are invisible fences and silent whistles for dogs.

CHAPTER 11B

MANAGEMENT OF WILD ANIMALS

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Overview

Wild animals exhibit a remarkable range of biodiversity and possess distinct attributes that set them apart from domesticated companion animals. A comprehensive understanding of the principles and practices of wild animal management is imperative for the provision of veterinary care and the implementation of conservation efforts for these species. The chapter commences by introducing contemporary technologies utilized in the conservation of wild animals in their natural habitats (in-situ) as well as in controlled environments (ex-situ). Subsequently, the chapter presents a set of guidelines pertaining to the appropriate handling of wild animals, encompassing techniques for restraining them and offering practical demonstrations. The topic of animal rights and welfare considerations in the handling and care of animals is briefly addressed. The discussion also encompasses fundamental principles pertaining to the conservation of wild animals, specifically focusing on in-situ and ex-situ conservation methods, population control strategies, and the implementation of environmental enrichment measures. The presentation also emphasizes the various breeds and husbandry practices of camels and equids, in addition to discussing hoof care and stable management. The chapter culminates with practical exercises pertaining to the management of large herbivores through the implementation of restraint techniques.

Objectives

The objectives of this course are to:

1. describe modern technologies in the management and care of companion animals;
2. explain the principles of wild animal handling;
3. demonstrate how to prevent injuries in the process of handling wild animals; and
4. explain the conservation of wild animals.

Modern Technologies in Management and Health of Wild Animals

Modern Technologies for Wild Animals in In-situ Conservation

1. Bio-logging and Bio-telemetry

Bio-logging and bio-telemetry have distinct ways of collecting information though both involve the monitoring of behavioral, physiological, or organism's environmental data which are perceived challenging to observe or probable inaccessible (Boyd *et al.,* 2004; Cooke, 2008). Whilst bio-logging takes records and stores information within an animal-borne device (archival logger) with the information downloadable once the logger is retrieved, bio-telemetry on the other hand sends the information to a waiting receiver which derived from the animal-carried device (Cooke, 2008). According to Block (2005), novel approaches involving both technologies are improving the capacity to accomplish ecosystem-scale science which is assisting scientists in exploring yet-to-be-answered ecological questions. Also, Assisted Reproductive Technologies (ARTs) are being used in the conservation of endangered species. These techniques such as In-Vitro Fertilization (IVF) and Artificial Insemination (AI) allow for the reproduction of animals that may not be able to breed naturally. This is particularly useful for endangered species with low fertility rates or those that are geographically isolated. By using ARTs, scientists can

produce viable offspring and help boost populations of endangered species.

2. Camera traps

Camera traps are remote devices usually equipped with a motion or infra-red sensor which automatically record images or videos (Nazir *et al*., 2017). They have emerged as a vital wildlife research tool and have afforded researchers the opportunity to monitor larger populations of wildlife. Traditional methods including visual, trapping and capture methods are often labor-intensive. However, camera traps can increase observers' number whilst making them more cost efficient (Welbourne *et al*., 2017). Utilization of this technology has aided in addressing questions of species' activity patterns, distribution and population densities (Frey *et al*., 2017). More significantly, camera traps offer a hands-on approach to answering several questions regarding wildlife besides animal population estimation. Behavioral studies involving the use of camera traps help us fathom how different species utilize their habitat (Cutler and Swann, 1999).

Handling of wild animals

It is important to note that working in close contact with animals requires skills which are developed in training and over time in practice. Most animals do not like handling or restraint or incursion into their spaces. Risks involved in handling animals could range from slight discomforts to life threatening physical and medical conditions. These risks could be immediate or develop over time depending on the degrees and duration of exposure. Most animals will physically defend or express themselves using horns, head butts, kicks, bites, scratches/injuries from claws, talons, beaks, tail swipes, body shoves and spitting. Most injuries or risks are encountered mostly due to improper appraisal of the animal(s) to be handled.

It is recommended that students and practitioners assess the **"7Ss" (Species, Sex, Status, Situation, Solution, Safety and Surprise)** before approaching animals.

Species: What species is this animal? What class of injury is expected? What is the natural response of such species to the activities happening around them? Is the animal a reptile, primate, small or big cat, etc.?

Sex: Is the animal male or female? What gender is accorded leadership and /or protective status amongst the species in question?

Status: Is the animal old or young? Is the animal in close-up quarters, free-ranging or escaped from confinement? Is the animal nursing, carrying baby, low ranking or highly ranked?

Situation: What is happening? Escapes, Human-wildlife conflict? Injuries within the group, disease outbreak, relocation or routine interventions.

Solution: What the Veterinarian has been called to handle versus what should be done to manage the situation versus what is the applicable solution? There are instances that these questions do not have same answers. Solutions will depend on other factors including the capability of the responders and the clients.

Safety: The safety of the animals to be handled and the humans involved in the handling exercise is paramount and must not be seen as less important to the other considerations.

Surprises: It is essential to think about and have alternate plans. There are tendencies for surprises either from the animal or human end. There are instances when things do not go as planned.

It is germane to assess the "7Ss" holistically (as they are interrelated) and ensure that successful animal handling is achieved.

Likely risks while handling animals may include:

a. Injuries - from kicks, bites, irritants, body shoves, falls from missteps.

b. Zoonoses - exposure to pathogens or diseases that are transmissible from animals to humans (and vice versa) arising from infections, contacts with parasites, body fluids carrying microorganisms.

c. Physical ailments from injuries, stress of handling animals in unprofessional ways.

d. Development of mild to life threatening allergies to dander, furs, feathers, environmental allergens, and animal secretions.

Prevention of injuries

a. Handlers must understand the behaviour and reactions of species to be restrained.
b. Wearing of Personal Protective Equipment (PPE) while handling animals. PPE include gloves, boots, coveralls, protective goggles, etc.
c. It is dangerous to assume that the animals are well studied and thus predictable. **Never Assume**!

Introduction to restraint techniques

Restraint generally implies the inhibition, hindrance or restriction of animal movement. In essence, it is an attempt to cordon, limit, moderate or control the activities of an animal for a specific period and purpose. The restraint technique must be tailored to suit such purpose. Restraining animals properly is a prerequisite towards effective performance of most veterinary related activities on an animal (Figures 1 and 2). It is important to note that the goal of all restraint is to get the exercise done with minimal level of stress to the animals and handlers (Hassan and Nwannenna *et al.,* 2009).

Figure 1: Demonstration of physical restraint of a venomous forest cobra to veterinary students.

Figure 2: Demonstration of restraint of a non-venomous snake.

Why do we need to restrain animals?

Quarantine evaluations, routine examinations, wound and fracture repairs, assisted deliveries and other surgeries, translocation/relocation, retrieval of escapee animals, shelter of stray animals, capture, etc.

Qualities of ideal restraint methods:

1. It must be as safe as possible to the team and target animals.
2. It must consider the temperament of the animal.
3. It must not interfere with the basic freedom of the animal.
4. It must be able to achieve the purpose for restraint/capture.

5. It must put the **7Ss** into consideration.

Handling Non-Human Primates

Primates make up one of the Orders within the Class Mammalia and are one of the most species-rich among mammals. Non-Human Primates (NHPs) are other primates aside humans (*Homo sapiens*). Although wildlife practice is a budding aspect of Veterinary specialties in Nigeria, the NHPs are currently one of the most encountered wildlife species either presented in general practice or zoological exhibits. The 7S is a must considered factor in handling and restraint of NHPs. The target is to have a cooperating NHP with considerably reduced risk of injury and stress to the animals and handlers. Non-Human Primates can be handled using the 3Ps – Physical, Psychological or Pharmacological means, or a combination of two or all the three means.

Physical - The use of hands, grabbing by the scruff, netting (scoop or drag nets) (Figure 3), use of improvised non-injurious snares and squeeze cages. Physical means are mostly deployed when the animal is housed in smaller compartments and on small-sized animals.

Figure 3. Scoop net being used on a juvenile drill monkey in a confined space.

Psychological - This is the use of baits and bits of tricks. It mostly involves luring an animal into a place or space where the handlers have a better advantage in terms of achieving the aims of restraint. It is simply the use of the biology/behaviour (food, mating choice, past history, vocalization, eye contacts, gestures) of the animal to achieve restraint.

Pharmacological (Chemical) - This is the use of pharmacological agents (muscle relaxants, sedatives, anaesthetics, and tranquilizers) to render an animal partially or completely non-reactive to external stimulus. The depth and choice of these agents depend on the purpose(s) of restraint and a careful evaluation of important factors. This can be achieved via oral dosing, hand injection or remote delivery through blow pipes or dart rifles (Egbetade *et al*., 2016).

In most instances, a critical evaluation of the 7Ss will give directions on which method to use or combine for restraint. Handling of NHPs requires a combination of Veterinary skills and science.

Restraint Techniques and handling of Snakes

Snakes display a wide diversity in physiology, morphology, activity levels, food habits, and many other biological parameters. All snakes have the capability to bite. Therefore, they require a level of carefulness especially in venomous species that require special training in handling.

The selection of restraint and handling technique in ophidians is largely dependent on the following:

- Snake species – Elapid, pythonid, colubrid, etc.
- Venomosity – Non-venomous, mildly venomous, venomous.
- Tools available.
- Dentition – Proteroglyph, opisthoglyph, solenoglyph, aglyph.
- Size – Large, medium or small.
- Purpose – examination, force-feeding, cleaning, medication, etc.

Techniques

Physical restraint – This involves the use of hands or other tools to restrain or handle snakes.

- Grab the head behind the mandible, support the rest of the body with the other hand.
- If a snake is long and heavy, two or three people should support the length (one person per 3-4 feet) to protect the spine (Snakes should not be pinch-grabbed but supported from underneath).
- The mouth of a correctly held ophidian can be opened either by pulling on the loose skinfold between the mandibles or by gently inserting a plastic spatula or covered forceps into the mouth, taking precautions to prevent tooth damage.
- For coccygeal venipuncture, the tail should be lower than the head to promote blood pooling in the tail.
- Never allow a large snake to throw a loop around the neck or body of a handler. A snake would naturally coil; therefore, it is better to be around an arm. This is safer for both snake and handler.
- Use tongs or hooks to grab, pin or lift the snake.
- Other tools include double-layered or maille gloves, small plastic shield, transparent tubes, snake sacks and face shields for spitters.

Chemical restraint – This involves the use of anaesthetic agents and other drugs.

Injectable: Ketamine 5–20 mg/kg, Xylazine 0.2-0.4mg/kg, etc.

Inhalant: Isoflurane 1.5–2.1%, etc.

Figure 4: African rock python under anaesthesia.

Animal Rights and Welfare Consideration in the Handling and Care of Animals

Animal Rights and Welfare

Animal rights refer to the credence that animals have inherent value and deserve to be treated with respect and dignity. This includes the right to life, freedom from suffering, and the ability to live according to their natural instincts. It is a viewpoint which postulates that animals should not be used for any reason by humans, which may include labour, food, entertainment and other purposes for which animals are utilized in present-day society. Animal rights activists have a precise focus in mind which is "*Ending the use of animals by humans*". Animal welfare, on the other hand, focuses on ensuring that animals are provided with appropriate care and protection from harm. It refers to the quality of life of an animal and how well animals are thriving within

their environment. This approach is basically enshrined in science and makes judgments based on observable facts. Animal welfare organizations ensure that animals have progressive social and physical experiences in their lives.

When handling and caring for animals, it is sacrosanct to consider their exact needs and preferences such as making provision for adequate food, shelter, water, and medical care, as well as making sure that their environment is safe and free from hazards. It also means avoiding practices that cause them unnecessary stress, such as overcrowding or rough handling. Animal welfare considerations are particularly important in industries such as farming, research, and entertainment, where animals may be used for human purposes. It is essential to ensure that animals are treated with utmost care. The failure or success of animal welfare is often measured by five freedoms (Freedom from hunger and thirst; Freedom from injury, pain, disease; Freedom form discomfort; Freedom to express normal behaviour; and Freedom from distress and fears). These freedoms provide a valued and all-inclusive framework for evaluating welfare and assist in ensuring that certain welfare determinants like alleviation of pain are not considered at the exclusion of other key determinants such as providing a suitable environment that allows expression of normal behaviour. Coincidentally, these 'freedoms' have recently been redrafted to be five domains which are nutrition, behavior, health, environment, and mental state.

Good animal welfare necessitates disease prevention and veterinary treatment, humane handling, appropriate shelter, nutrition, management, and humane slaughter. According to Omonona and Ayodele (2011), animal welfare covers the full spectrum of animal feeling which covers its physical and emotional state. Safeguarding an animal's welfare infers that its mental and physical needs are provided for. Regard for animal welfare is based on the premise that non-human animals are sentient, and that utmost consideration ought to be given to their well-being especially when they are under human care (Animal Liberation, 2004). There are also diverse ways of assessing animal

welfare, which includes but not exclusive to productivity, health, physiological responses, and behaviour.

Considerations in Handling

Animals perceive their environment differently from humans. They have extremely sensitive hearing capacity which can detect sounds that human ears may not hear. Loud noises startle animals, and research has proven that high-frequency sounds really inflict hurt in their ears. This explains the reason why animals are edgy mostly in unacquainted milieus. Observing animals for possible signs of ferociousness or fear often signifies possible danger. Although handling methods may differ immensely for different animal species, there are some generally recognized considerations with regards to working with an animal:

9. Most animals will ultimately adjust to routine; so, be deliberate and calm.
10. Avoid loud noises or quick movements.
11. Be patient; do not nudge an animal especially when it has nowhere to go.
12. Give rewarding respect to animals.
13. Always have a plan or route for escape particularly when working in close animal confinement.

Though animal welfare and rights are clearly distinctive, they both address the concept of treating animals with caution. Considerations must always be given utmost priority when handling animals.

In-Situ & Ex-Situ Conservation, Population Control of Wild Animals and Environmental Enrichment

Wild Animals in In-Situ and Ex-Situ Conservation

Wild Animals in in-situ conservation are animals conserved in their natural environment. Such environments are usually referred to as protected areas, which are mostly national parks and forest reserves, but could also include wildlife sanctuaries and conservation centres. In situ conservation attempts to protect animals in their natural habitat. It

aims to preserve the natural habitats and ecosystems of wild animals and maintain their ecological processes and functions. This approach involves various activities such as protected areas, wildlife corridors, habitat restoration, sustainable use, and translocation. On the other hand, a wild animal which is held under confinement and depends on humans for all its needs is said to be in captivity. Such animal is termed to be in an "ex-situ" conservation area. It involves the conservation of wild animal species outside their natural habitats, such as zoos, wildlife sanctuaries, and breeding centers. Zoos and wildlife sanctuaries provide a safe and controlled environment for wild animals where their health and welfare can be monitored and managed.

Wild Animal Care and Management in In-situ and Ex-situ Conservation

Wild animal care and management refers to the various activities and techniques used to certify the health, welfare, and survival of wild animals in their natural habitats or under human care. These activities are essential for maintaining the ecological balance and functioning of ecosystems, protecting biodiversity, and promoting human well-being. There are many examples of good management and care practices for wild animals in conservation. However, some captive wild animals still somewhat suffer due to poor welfare standards. Some better care and management practices for wild animals in conservation are discussed below.

Animal Hygiene

It refers to animal health care practices including each form of interaction between the biotic and abiotic environmental components as well as strategies put in place to prevent diseases, ensure that age and species-specific welfare needs of animals are met whilst promoting their health. Hygiene is of extreme importance to animal health and starts with basic design of animal enclosures. The ease of cleaning should be seen as very imperative while proper disinfection is a must.

Quarantine

Quarantine is a very familiar terminology used both in veterinary and medical sciences. It implies obligatory detention or isolation to forestall spread of infection. The major aim of quarantine is to allow the detection of animal species that may be nurturing certain diseases with short periods of incubation and to identify clinical signs of disease with a longer period of incubation. Quarantine should last a minimum of 30 days and ought to be under the direct supervision of a Veterinarian (Omonona and Kayode, 2011). During quarantine, animals should obtain suitable diagnostic testing and vaccinations. They should be examined and treated for ecto- and endoparasites as well as screened for any enteric bacterial pathogens.

Health and Safety

Health and safety-related issues are becoming subjects of global concern due to their knowledge and sensitivity to their existence (Omonona et al., 2018). Health and safety are crucially vital aspects of ex-situ conservation, particularly management. Preventive measures and good hygiene should be put in place to avert diseases. This is because a wide variety of health and safety risks are often encountered by employees (especially in ex-situ conservation areas) including animal bites, animal escape, infections, back injuries, etc. (Kabuusu *et al.*, 2010). Hence, there is a crucial need to evaluate emergency preparedness, health and safety measures in conservation so as to ensure and guarantee the well-being of both zoo employees and visitors, and not excluding animal welfare (Omonona *et al.*, 2018).

Vaccination

Vaccination programs for all species or groups of animals should be developed. Specifically, vaccination of zoo carnivores is necessary due to their susceptibility to different diseases like feline rhinotracheitis, canine distemper, feline panleukopenia, rabies, feline calicivirus, and canine parvovirus (Omonona and Ayodele, 2011). The decision to vaccinate zoo animals for less common diseases for which a vaccine is readily available should be made on an individual basis.

Wild Animal Population Control

The management of wild populations can be described as human interventions which are imperative to control wild animal populations to enable human safety. It is an essential aspect of wild animal care and management, especially in cases where wild animal populations are overabundant or pose a threat to human safety or livelihoods. Population control techniques include hunting, trapping, contraception, sterilization, and culling. If the methods used to catch animals are not humane, their welfare may be compromised in different ways. In those animals that are being culled, the method of killing must be humane, otherwise severe, suffering, pain and distress may be inflicted on animals that are injured, but not killed (e.g., wounded animals that escape). If only specific group members or population are culled or relocated, it could lead to considerable distress to other members of that social group because of separation, increased predation or competition with other groups, or loss of the pack or herd leader.

Environmental Enrichment

Environmental enrichment is one of the most widely used and popular methods of improving the way in which captive wild animals are kept so that their life in captivity meets their needs. It is a crucial aspect of wild animal care and management, especially in captive environments, where wild animals are deprived of their natural habitats and behaviors. Environmental enrichment involves providing wild animals with a variety of stimuli such as toys, puzzles, and food puzzles, to promote their physical and mental well-being. Briefly, the principle of environmental enrichment can be thought of as how the environments of captive animals can be changed for the benefit of their inhabitants. The type of enrichments that are given to captive wild animals should be dependent on the reason for keeping the animals. For the long-term residents (who are likely to spend longer periods or lifetime in captivity), enrichment must mimic only the salient positive features of the natural environment that enhance welfare. For instance, the environment must have some complexity, provide stimulation, promote natural behaviours, house animals from social species groups, etc.

Wild animal care and management are essential for the long-term conservation and sustainability of wild animal populations and their habitats. In-situ and ex-situ conservation approaches, population control techniques, and environment enrichment are some of the methods used to promote the health, welfare, and survival of wild animals.

Breeds and Husbandry of Camels, Horses, Donkeys, and their Uses. Care of the Hoof. Stable Management

Horses

The horse is a domesticated, one-toed, hoofed mammal. Nigerian indigenous horses are a mix of Arewa and their crosses with Arabian, Dongola, and Sudanese breeds. Other exotic breeds found in Nigeria include the Argentine and Arabian breeds.

Their uses include transportation, cultural heritage and royalty (ornamental), recreation and companionship, as calvary animals in military and para-military forces as well as in ceremonial events. they are also used for sports and entertainment events like Polo and racing.

Donkeys

The domestic donkey is a hoofed mammal in the family Equidae. Donkeys are usually distinguished by their coat colour. Four breeds or types of donkeys are recognized in Nigeria i.e., *Auraki*/Rust or red, *Duni*/Dark brown to black, *Fari*/Pale cream to white and *Idabari*/Grey to light-medium brown.

They are used as beasts of burden; for plowing and carting in farms by pastoralists and farmers. They are also used for transportation and consumed as meat.

Camels

There are two living species of Old-World camelids, the Bactrian camel and the dromedary. The dromedary camel, which is the species found in Nigeria, forms 94% of entire world population and is an even-toed

large ungulate, possessing just one back-hump. Camels have special physiological mechanisms that enable them to endure harsh environments and extremely high and low temperatures. The camel's physiological response to high temperatures is good, with blood volume maintained in part by water being redirected from the skin to other body parts like tissues and organs.

Camels supply meat and milk for human consumption. Also, they supply hide, hair and skin. They are used as beasts of burden and in sports and entertainment.

Husbandry

Husbandry guidelines serve as an important source of reference on the maintenance, restraint, diet and breeding of animals held in captivity (Table 1).

Table 1: Husbandry guidelines

Animal	**Terminologies**	**Reproduction**	**Space requirement**	**Bedding/ substrate**	**Diet**	**ID methods**
Horse	Male – stallion Female - mare Young - foal	Gestation-335–342 days SM- F (1-1.5 years) M (1.5-3 years)	A 12-foot x 12-foot stall for a 450kg horse. Generally, 1.5times the horse's length	sand, soil, straw, hay	Primarily grazers Forage diet of grasses and other plant material , consumed steadily throughout the day	Microchipping, Tattoos, Markings, brands, freeze marks
Donkey	Male – Jack Female - Jennet Young - foal	Gestation-365 days SM- F (1-2 years) M (2-3 years)	4.5m^2 (50 $feet^2$) of covered area per donkey, about 9m^2 (100 $feet^2$) for a pair	sand, soil, straw, hay	Primarily grazers Forage or hay 1:4 ratio of legumes to grass	Microchipping, Tattoos, brands, freeze marks
Camel	Male – Bull Female - Cow Young - calves	Gestation-365-400 days SM- F (3-5 years) M (5-6 years)	100m^2 50m^2 (for every additional)	sand, soil, straw, hay	Primarily browsers. Thorny plants & dwarf shrubs (47%), trees (29%), grasses (12%),	Microchipping, ear tags, Tattoos, brands, freeze marks

					vines (11%) and other herbs (1%)	

SM – Sexual maturity

Care of the Hoof

Structures of the horse foot

External – Coronary band, periople, hoof wall, sole, frog.

Internal – Sensitive sole, digital cushion, lateral cartilages, laminae.

Conformation check

Check for symmetry.

The hoof wall ought to be smooth and without fissures. Any lines/cracks could be a sign of malnutrition or of previous resolved laminitis.

Poor foot conformation can result in strains to hoof ultrastructure like tendons and ligaments, as well as also tripping and bruising.

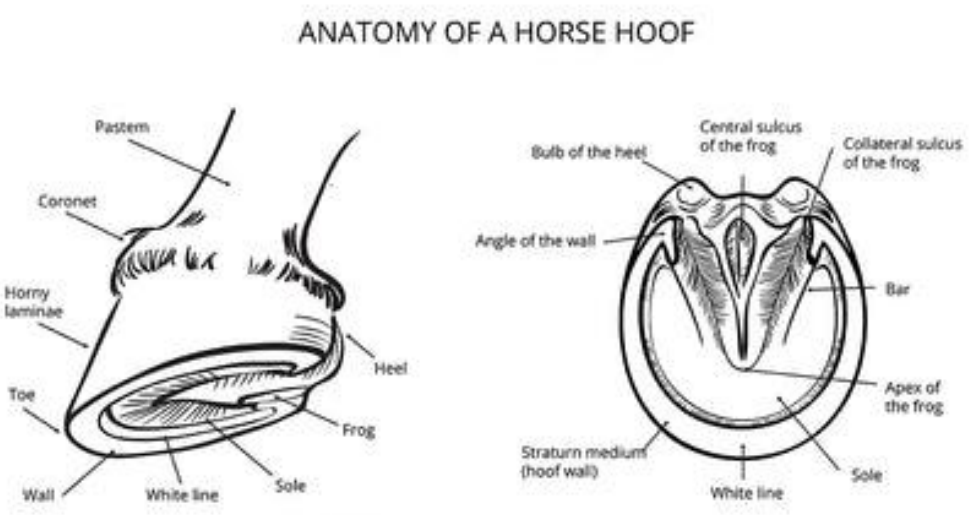

Figure 5: Horse hoof anatomy

Routine hoof care procedures for the horse

Hoof care is usually a farrier affair and involves the application of hoof oil (every other day), daily hoof-picking, inspection of the horseshoes for wear, and examination of the hooves for signs of uneven wear and overgrowth. Biotin supplementation should be administered to horses to promote hoof health.

Common disorders of the horse foot

The foot is typically the body part where lameness originates in most cases.

Bruised sole, thrush, seedy toe, laminitis, hoof abscess, nail bind/prick, sand/grass cracks.

Stable Management

Most important requirements for an equine stable

i. Must be a safe space for the horse and the staff working with them.

ii. Must have adequate room for the horse to move around.

iii. Must have adequate room for the people to safely work with and around the horse.

Shelter design, bedding provision, hygiene, and water and feed availability are important considerations when setting up or managing an equine stable.

Shelter

Important considerations when designing a stable are as follows:

• Adequate shelter from both sun and rain should always be available.

• Avoid construction materials which allow condensation to develop – especially roofing.

• Allow adequate floor and height space.

• A well-drained non-slip hard floor surface is essential e.g., concrete or stable brick.

• Provide a drained concrete run out yard.

• Ensure sufficient ventilation with good air circulation.

• When designing your stable, take wind direction into account and face the back into the wind.

• Stable doors must allow horses to see over with ease.

• Use wire mesh to shield glazed windows.

• A corner floor feeder or floor level feed bin that is positioned so that the feed is not soiled.

• Tying up rings should be fitted at the correct height for horses, usually at eye level.

• Stables or field shelters should be sited on well-drained ground, and fly-prone areas should be avoided.

Bedding

Sand, soil, straw, hay, etc. Mucking out - Wet patches or dung on beddings like straw, shavings, shredded wood fiber, or paper beds should be removed daily.

Hygiene

Hygiene and cleanliness are of utmost importance to the health and safety of the stable occupant.

Water

Horses should always have access to clean water supply.

Mineral lick

Equine mineral block should be utilized to supplement their diet as required. This should be hung up inside your stable or shelter for easy access.

Introduction to Restraint Techniques and Animal Handling of Herbivores

Due to the large size variation amongst animals in this group, picking the appropriate restraint techniques is very important. There are three types of restraints for herbivores: physical, chemical, and psychological restraint.

Physical restraint: Physical restraint refers to the use of hands, ropes or trap nets for small-sized herbivores or other physical or mechanical devices to restrain animals. This form of restraint is the most frequently employed in herbivores. Adequate knowledge on knots and knotting patterns is important in the implementation of various restraint techniques in herbivores from tying to halter to casting methods.

Figure 6: Casted camel with twitch applied.

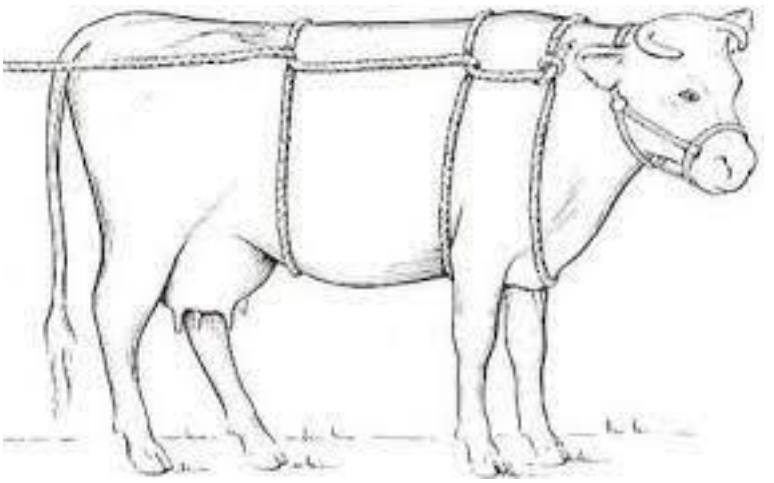

Figure 7: Casting bull

Chemical restraint: This mainly involves the use of chemical substances to calm animals sufficiently to permit examinations or performing desired procedures. Various drugs have been used to achieve chemical restraint most of which selectively depress the nervous system to produce the desired effect. Common classes of drugs that have been used for chemical restraint are tranquilizers, muscle relaxants, sedatives, anesthetics and hypnotics. Specific dosages and mode of administration can be found in drug formularies.

Psychological restraint: Psychological restraint or moral persuasion, though often overlooked, is the easiest restraint method to apply and it is effective. This form of restraint has often been employed in the restraint of pets and horses. Though rarely used alone, it permits performance of a range of activities using very minimal additional physical restraint. For example, in horses, a direct and confident approach within the visible rather than the blind spots (directly in front and behind a horse) tend to calm and assure the horse.

1. Figure 8. Combination of Physical (Grabbing with protective gloves) and Psychological (Hood on the Head) restraint of a kite.

Exercises

Practical demonstrations on farm animal restraint techniques

1. Knots and knotting patterns e.g., square, granny, surgeon's, reef's, slip, etc.
2. Leading a horse.
3. Twitches.
4. Raising the horse limbs.
5. Applying halters and hobbles.
6. Casting of Horse, Donkey and Camels.

Practical demonstrations on snake restraints

1. Using a non-venomous species, demonstrate and practice picking up a snake.
2. Practice snake head and body restraints.
3. Practice use of tongs and hooks.

Practical activity on hoof management

1. Identification of parts of the hoof.
2. Use of hoof pick and hoof tester.

Practical activity on environmental enrichment

Go on field trip to observe wild animal species, mention at least three environmental enrichment options, and explain the importance of the knowledge of animal behavior in selecting suitable enrichments.

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Omonona, Abosede Olayemi specialized in Wildlife and Environmental Health having caught her first tooth in Veterinary Medicine from the renowned Faculty of Veterinary Medicine, University of Ibadan (1994) followed by Masters of Veterinary Science (1997) from the same Faculty. She proceeded to bag her PhD in Wildlife Management (2005) with special focus on some zoonotic-parasitic helminthes in wildlife, domestic animals and human interface in the defunct Yankari National Park, now Yankari Game Reserve. She has successfully supervised over thirty BSc projects, four Postgraduate diploma projects; 20 MSc projects; three PhD projects while 4 PhD projects are currently on-going. She is the current Head of Department of Wildlife and Ecotourism Management, University of Ibadan, and a member of the University of Ibadan Zoological Gardens Management Board. She possesses experience in management of wildlife health in both in-situ and ex-situ conservation areas.

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Chapter 12

VHM 203: Poultry and Fish Production and Management

Chapter 12A

Poultry Production and Management

Chuka Ezema, *University of Nigeria, Nsukka,* **Negedu Onogu Ameji,** *University of Jos, Jos* and **Omolade Oladele,** *University of Ibadan, Ibadan*

Overview

The poultry industry is a very important sector of animal agriculture in Nigeria. It is one of the most viable and popular agricultural enterprises in the country. Poultry production has grown from small householder business to a multibillion-naira venture employing hundreds of thousands of people, both in the rural and urban communities in Nigeria. Poultry production is a major source of animal protein supply in many developing countries including Nigeria. It also makes a significant contribution to our national Gross Domestic Product (GDP).

The poultry industry has many branches. Two main branches are commercial layers (table egg production) and broilers (meat production). Other branches include breeders (parents) stock (for fertile egg production), hatchery operation (for day-old chicks production), poultry feed manufacturing, manufacturing of poultry equipment, and manufacturing and marketing of poultry drugs and vaccines.

In Nigeria, poultry production has some challenges including high cost of feed (partly due to competition for cereal grains between man and other livestock), lack of financial capital and poultry diseases.

Objectives

The objectives of this course are to:

1. identify the origin, breeds/types and importance of the domestic fowl;
2. identify the breeds/types and economic importance of other poultry species;
3. discuss the management techniques for intensive chicken production;
4. describe the production processes and management systems for the various types of poultry species;
5. explain housing, feeding and basic health management practices necessary for poultry and ostrich production;
6. describe breeder farm management techniques; and
7. identify hatchery equipment and explain hatchery operations.

Classification of Poultry and other Birds

Classification of birds is based on the 7-level classification system of organisms into Kingdom (Animalia); Phylum (Chordata); Class (Aves); Order (≥ 27 Orders); Family (142 families) and Species (≥9,700 species) with derived naming based on the binomial naming system of Carl Linnaeus, using the Genus and Species combined.

Poultry species are domesticated birds derived from two Orders i.e., Galliformes (Wildfowls or Land fowls) and Anseriformes (Waterfowls) that are reared for different purposes. The Galliformes and Anseriformes are closely related and were once thought to be in the same Order, commonly referred to as the Galloanseres. Members of these Orders and their Families are:

1. Order: **Galliformes**

i. Meleagridae – Turkeys (*Meleagris gallopavo*)
ii. Numididae – Guinea fowls (*Numida meleagris*)
iii. Phasianidae – Chickens (*Gallus gallus domesticus*); Peafowl (*Pavo cristacus*); Pheasants (*Phasianus colchicus*); Quails (*Coturnix coturnix japonica)*

2. Order: **Anseriformes**
   i. Anatidae – Mallard duck (*Anas platyrhynchos*); Goose (*Anser anser)*; Muscovy duck (*Cairina moschata*)

History of the Domestic Fowl

The domestic fowl originated mainly from the red jungle fowl (*Gallus gallus*) with some contributions from the Grey Jungle fowl (*Gallus sonnaratti*) and Javan Jungle fowl (*Gallus varius*) in Southeast Asia and Oceania around 3000 to 2000 BC. The domesticated chickens later spread to other parts of the world.

Breeds and Types of Chickens

In the classification of breeds and types of chickens, there are descriptive terms used which require definition, namely: ***Species***, ***Class, Breed, Variety, Strain, Pureline, Grandparents***, ***Parents*** and ***Commercials***.

Poultry is any bird domesticated for useful purpose. There are many breeds of poultry. For production purposes, two main breeds/types and their crosses are important.

1. Local breeds/types: The Nigerian indigenous chickens are grouped under two ecotypes which are: ***The Sahel/Fulani ecotype***; found in the Sahel and Guinea savannah regions of northern Nigeria and ***The Forest-Savannah/Yoruba ecotype***; found in the rainforest and swampy areas of Nigeria. Other types include the *Frizzled* and *Naked Neck* chicken. These local breeds/types are characterized by slow growth rate, poor egg yield and production of small sized eggs. They are resistant to the tropical environment as well as common poultry diseases.

2. Exotic breeds: These are original breeds such as Leghorns, Rhode Island Red, New Hampshire, Plymouth Rock, etc. They have all undergone extensive genetic engineering such that today, they are only known by the companies that breed them. Significantly, two strains have been developed – heavy strain (broilers) for meat and light strain (pullets) for egg production. However, the exotic breeds are more susceptible to harsh tropical conditions and common poultry diseases.

Poultry Production and Management Systems

Basically, poultry (livestock) production is classified based on either the scale or type as:

1. ***Based on scale of production***
2. ***Based on type of production***

On the other hand, the management systems are classified as follows:

1. ***Traditional/extensive and semi-intensive***
2. ***Conventional/intensive***

Requirements for Poultry Production

Housing and production pens

Regardless of the species of poultry, housing provides protection to the birds against harsh weather, predation and theft, provides ease of management, and protects against disease entry and spread within flocks and on the farm. It is a basic requirement in any of the three systems of poultry farming: a) *Extensive poultry farming system;* b) *Semi-intensive poultry farming system;* c) *Intensive poultry farming system.*

Housing can be of any of these types: *Crib/fold unit movable housing, Portable or fixed cage housing and Standard fixed poultry housing.*

In the tropics, the standard poultry house is a short wall (about 3 coaches of block) and wire net to the roof. The roof top should also

have small opening on both sides. This is essential to ensure proper ventilation and minimize ammonia build up and stress in the pen.

Recommended feeding, drinking and resting space:
Open-sided house with a short wall and net

	Broiler	**Pullet**	**Pullet**
	0 – 8 wks	9 – 20 wks	> 20 wks
Floor space (m^2/bird)	0.07 – 0.15	0.18 – 0.20	0.37
Feeding space (cm/bird)	2.5	7.5 – 12	15
Drinking space (cm/bird)	1- 2.5	2.5 – 5	10

Management Techniques in Chicken Production

Brooding and rearing management

Brooding is the care of the chick from day-old to about four weeks old. This care involves provision of warmth, feed, water and light to create a conducive environment for the chick's early life.

Why do we brood chicks?

We brood chicks within their first few weeks of life for the following reasons:

i. The day-old chick (DOC) is not completely homoeothermic. It is partially poikilothermic which means that it tends to take up the temperature of any environment it finds itself.
ii. The temperature of DOC is 39^{o}C which is lower than the adult temperature (41.1^{o}C). It takes at least 5 days for the DOC to attain the adult temperature.
iii. Down feathers of the DOC cannot sufficiently insulate the chick at this age.

iv. At this early age, the air sacs are active and gaseous exchange is taking place through them. Should the chicks be exposed to a cold environment, they can die of chilling.
v. The superficial blood vessels are covered by a thin layer of skin which may permit loss of heat.

Specific brooding activities

N.B: Source chicks from reputable hatchery after confirming their quality from farmers that have reared them recently. No amount of care or good management will make a poor-quality chick to perform well.

Preparation for brooding and arrival of the chicks.

Brooding temperature

The recommended brooding temperature at the litter level are:
1st week 32.2°C – 35.0°C, 2nd week 29.7°C – 32.2°C, 3rd week 26.6°C – 29.7°C.
Monitor the chicks to ensure that the brooding temperature is adequate.

Figure 1: Gas powered brooder

Figure 2: Charcoal pot brooder

Relative humidity
The ideal relative humidity for chicks is 50 – 70%.

Ventilation
Proper ventilation is very important to minimize ammonia stress. Optimum air quality at the chick level are: Oxygen – 19.5%, Carbon dioxide – < 3000 ppm, ammonia - < 10 ppm, dust level – 3.4 mg/m^3.

Light
Light should be provided every night to enable the chicks to see, eat and drink.

Rearing management
Transfer to the rearing pen.

Routine management
Occasional management operations: such as debeaking (beak trimming) in pullets.

Feeds and Feeding Management

Broilers: In modern broiler business, the production target is to finish birds in 6 weeks with 2.5 – 3 kg/bird live weight. Broilers are fed *ad libitum.* The strategy to achieve this target is as follows:

Age (weeks).	*Type of Feed*	*Crude Protein (CP) (%)*	*Metabolizable Energy(ME) (kcal/kg)*
0 -2	Broiler super starter	23 -24	2800
2 – 4	Ordinary broiler starter	20 – 21	2900
4 – 6	Broiler super finisher	19 – 20	3000

Due to high tropical ambient temperature, the birds require higher protein to increase their voluntary feed intake.

Pullets: They are fed chick mash (18 – 19% CP and 2800 kcal/kg ME) for 8 weeks. At this stage, pullets are fed *ad libitum*. Between the 9th week and point of lay, their feeding management is restricted both in quantity and quality to prevent precocious maturity. They are given grower mash (15% CP and 2650 kcal/kg ME). The quantity is maintained at 100gm/bird/day until point of lay. From the first egg drop, they are given a mixture of layers' mash (17% CP and 2700 kcal/kg ME) and grower mash (50:50) for two weeks. Thereafter, they are placed on layers' mash at 120 to 125 gm/bird/day depending on the breed.

Normal laying pattern

The domestic fowl (exotic breed) has a defined laying pattern. Egg production within the laying year is divided into 3 stages namely, ***phase 1, phase 2 and phase 3.***

After molting, the bird will start the second laying year (Hen year). The hen year follows the same pattern of 3 stages as in pullet year (first year). The difference is that the peak of egg production is about 20% less in the second year. However, egg size is normally bigger in the second year and the layers are also heavier.

Evaluating the performance of a laying flock

The following criteria are employed in assessing the performance of a laying flock:

a. ***Egg numbers b. Egg quality (egg size, shell thickness, egg weight) and c. Mortality***

Diseases of Poultry and Preventive Healthcare

There are several diseases of poultry species which adversely affect productivity. Also, there are several sources or portals of entry of diseases into the poultry farm. The important potential routes of disease entry include *litter material, poultry house/pen, poultry and other livestock, dead birds/animals, wild birds, feed and water, air and dust particles, equipment and vehicles, farm workers and visitors, rodents and other pests* and *expired/contaminated drugs and vaccines.*

The knowledge of the routes of disease entry helps in the appropriate implementation of the three preventive healthcare measures (prophylaxis) which are:

1. ***Biosecurity*** 2. ***Vaccination*** 3. ***Chemoprophylaxis***

Biosecurity

It involves all the management practices used to prevent disease entry into a flock and/or spread between flocks in a farm. The main objectives of biosecurity are bio-exclusion (keeping disease away) and bio-containment (keeping disease within from spreading out) with three implementation parts which are*: traffic/movement control, isolation of birds based on health status, age, batch or type, and sanitation (cleaning and disinfection).*

Vaccination

Vaccination is the process of introducing disease pathogens into animals/birds to cause such recipients to produce antibodies which are readily available to prevent disease outbreak when a field infection

occurs. The pathogens (vaccines) are either of reduced strength (attenuated) or naturally mild strains such that they are incapable of causing disease outbreaks. Examples of such vaccines used in poultry production are infectious bursal disease, Newcastle disease, infectious bronchitis, egg drop syndrome and others.

Chemoprophylaxis

Chemoprophylaxis is the use of chemical agents to prevent infectious diseases. These chemicals could be disinfectants or antibiotics.

Breeds of Ducks

Duck breeds are derived from the wild Mallard ducks (*Anas platyrhynchos*) and the Muscovy ducks (C*airina moschata*) which are broadly classified into three types:

1) ***Egg type duck breeds.*** Examples include *Khaki Campbell* and *Indian Runner*.

2) ***Meat type duck breeds.*** Examples include *Aylesbury, White Pekin,* and *Rouen.*

3) ***Ornamental type duck breeds***. Examples include *Call,* and *Crested White.*

Breeds of Turkeys

Turkeys are not classified as breed but as varieties or types. The present-day turkeys were developed from North American wild turkey. Seven standard varieties are recognized by the American Poultry Association. These are *Broad Breasted bronze (BBB), Beltsville Small White (BSW), White Holland, Bourbon red, Black, Slate,* and *Narrangansett*. The varieties of turkeys differ in plumage colour, size and meat characteristics, but the shape is common in general. Out of the seven varieties of turkeys, BBB and BSW are important from which most of the other varieties have been developed.

Breeds/Types of Guinea Fowls

The guinea fowls are game birds in the Family **Numididae**, native to West Africa and other sub-Saharan countries of Africa. There are several species of guinea fowls found in the wild but the two most common species are:

1. *The helmeted guinea fowls*
2. *The crested guinea fowls*

The helmeted guinea fowl is the most commonly seen species and has a horn or helmet on top of its head with a bright blue face and blue wattles with terminal red tips while the crested guinea fowl has a curly black "wig", called a crest on top of its head and no wattles.

The readily farmed type is the domestic guinea fowl which was a product of continuous breeding of the wild helmeted guinea fowl, *Numida meleagris* after domestication. The continuous breeding has led to the creation of three known varieties of domestic guinea fowl which are:

1. *Pearl Guinea fowl (purple to grey feather coloration, dotted with white)*
2. *Lavender Guinea fowl (pale/light grey or lavender coloration dotted with white)*
3. *Pure white Guinea fowl (pure white feather coloration with no speckle*)

Breeds/Types of Quails

Quails are small-sized game birds of the Order **Galliformes** placed in two families, **Phasianidae** and **Odontophoridae**. They resemble the partridges although they are less robust and smaller than the former. There are over 70 species in the **Phasianidae** which form the Old World quails while the species in the **Odontophoridae** are less and form the New World quails. Some common breeds of quails are Coturnix/Japanese quail (*Coturnix coturnix japonica*); Bobwhite quail (*Colinus spp*); Gambel quail (*Callipepla gambellii*); California quail

(*Callipepla californica*); The King quail (*Synoicus chinensis*); Mountain quail (*Oreotyx pictus*) and Elegant quail (*Callipepla douglasii*).

The predominantly farmed breeds of quail are the **Bobwhite** (*Colinus spp.*) and **Japanese** (*Coturnix spp.*) quails. The Japanese quail which is a dual-purpose breed is the breed that is found in Nigeria, introduced in 1992 at the National Veterinary Research Institute (NVRI), Vom, Plateau State. The Japanese quail has varieties such as *Pharaoh/Nile; English white, Manchurian gold; British range and Tuxedo.*

Production and Management of other Species of Poultry

Management of Ducks/Waterfowls

Ducks and other waterfowls are water birds which can swim and spend most life in water as their habitats, but they can also survive without water when kept in confinement or on free-range. However, water is required for reproduction and mating purposes. A shallow pond can be built in a courtyard where the birds are released during the day or right within the rearing pen to encourage mating and production of fertile eggs.

Production and Management Systems of Duck Farming

There are three major rearing and management systems of duck farming which are: a) Extensive/Free-range management system; b) Backyard/Semi-intensive management system; c) Intensive and or integrated management system.

Management and production parameters

- Age at maturity 5 to 6 months
- Body weight of egg type 1.5 to 2 kg
- Body weight of meat type 3 to 4.5 kg
- Feed consumption of adult 160 to 180 g/bird/day
- Egg production/bird/year 270 to 320 eggs
- Incubation period for Mallard duck 28 to 30 days
- Incubation period for Muscovy duck 36 to 40 days
- Male to female ratio 1 : 6 to 10
- Artificial brooding temperature (1^{st}, 2^{nd} and ≥ 3 weeks) 34, 30 and ≤ 21 ^{0}C
- Provide access to pond/surface water for breeding.
- Ducklings should be kept indoors for 2 to 3 weeks.

Feeds and feeding of ducks

Under the extensive or free-range management system, ducks scavenge and feed on grasses, seeds, insects and other feed resources from the pond bottom. However, under the backyard/semi-intensive and intensive systems, the feed must be provided in adequate amounts to balance the nutrient requirements. Feed should be fed wet to avoid wastage due to the spoon-shaped and serrated bills of ducks.

Common diseases of ducks

Ducks/waterfowls are hardy and relatively resistant to most avian diseases. However, under the intensive management system, the

following diseases can be of serious concern: *Salmonellosis/Keel disease of ducklings*, *Pasteurellosis/Riemerella anatipestifer infection*, *Colibacillosis, Botulism/Limber neck*, *Aspergillosis*, *Aflatoxicosis*, *Duck virus hepatitis/Wobbling disease of ducklings*, *Duck viral enteritis*, *Castor bean poisoning*, *External and internal parasitism*, *Nutritional deficiencies*, *Accidents/traumatic injuries.*

Production and Management of Guinea Fowls

Guinea fowls are game birds of the Family *Numididae* which is native to West Africa and other sub-Saharan countries. They are monogamous by nature with an adult male pairing with a female during the breeding season. There are several species of guinea fowls found in the wild, but the two most common species are: a) *The helmeted guinea fowl*; b) *The crested guinea fowl.*

Benefits of Guinea Fowl Farming

Guinea fowls are raised for various purposes such as economic, aesthetic, security alert as they serve as watch dogs and guarantee of food security.

Management and production parameters for Guinea fowls

- Age at maturity 6 to 7 months
- Body weight of adult 1.5 to 2 kg
- Feed consumption of adult 60 to 80 g/bird/day
- Egg production/bird/year 100 to 200 eggs
- Incubation period for Guineas eggs 27 to 28 days
- Male to female ratio 1 to 4 or 5

In addition, it is important to note the following about guinea fowls: i) *The hens are prolific and lay eggs daily during the laying season which starts from March/April to the month of October; ii) Keets should be kept indoor for 4 to 6 weeks; iii) The birds move together as a flock under free range but become monogamous during the breeding season; iv) The birds are generally active and resent handling especially by strangers which can make them aggressive; v) When kept under confinement, provide forage and grit frequently; vi) The hens are broody but have poor mothering ability so, chicken hens or artificial incubators are used to hatch their eggs.*

Feeds and feeding of guinea fowls

Birds kept under free-range management system scavenge and feed on grasses, seeds, insects and other feed resources from the field. However, under the backyard/semi-intensive and intensive systems, the feed must be provided in adequate amount to balance the nutrient requirements.

The nutrient requirements for guinea fowls under confinement are rich protein and energy diets equaling that of turkeys. However, where this rich protein diets are not available, they can be fed with chicken's starter and layer diets.

Diseases of guinea fowls

Guinea fowls are hardy and do not fall sick easily. They are not susceptible to most of the diseases of chickens. However, they may be affected by both infectious and noninfectious diseases such as *Newcastle disease, Avian pox, Infectious bronchitis, Marek's disease, Mycoplasmosis, Colibacillosis, Salmonellosis, Fowl cholera, Aspergillosis, Ecto/endo-parasitism, Accidents/traumatic injuries, Predation, Nutritional deficiencies, and Environmental toxicities.*

Production and Management of Turkeys

The turkey *(Meleagris gallopavo*) is a large gallinaceous bird of the Family ***Meleagridae*** that is native to North America. The domestic

turkey is derived from the wild turkey in Europe as a single breed from which several varieties have been developed.

Extensive/Free range management system:
Backyard/Semi-intensive management system:

Intensive and or integrated management system:

Management and production parameters for Turkey farming

- Sex ratio (Male: Female) 1:6
- Average egg weight 75 g
- Average day-old poult weight 60 g
- Age at sexual maturity 24 – 30 weeks
- Egg production per year 85 – 100 eggs
- Incubation Period 28 days
- Average adult weight 10 – 15 kg
- Egg production cycle 6 months
- Average feed consumption/bird up 5 months 19 – 23 Kg
- Mortality during brooding period 3-5%

During brooding, poults require a higher brooding temperature of about 35 to 36^0C than chickens in the first week which should be stepped down by 2 to 3^0C every week until 4 weeks of age. Within the first two days, poults have to be force fed or assisted in feeding by the inclusion of some day-old chicks to lead them to feeding and watering points.

Feeds and feeding of turkeys

Turkeys kept under free-range management system, scavenge and feed on grasses, seeds, insects and other feed resources. However, under the backyard/semi-intensive and intensive systems, the feed must be provided in adequate amounts to balance the nutrient requirements.

The nutrient requirements for turkeys under confinement are rich protein, vitamins/minerals and energy diets. The nutrient requirements for turkeys differ depending on age and stage of growth as shown below:

1. *Turkey starter feed fed from 0 – 8 weeks with 28% CP and ME of 2800 Kcal/kg.*
2. *Turkey grower feed fed from 8 – 16 weeks with 24% CP and ME of 3000 Kcal/kg.*
3. *Turkey finisher feed fed from 16 – 20 weeks with 18 – 20% CP and ME of 3200 Kcal/kg.*
4. *Turkey layer/breeder feed fed at > 20 weeks with 15 – 17% CP and ME of 2900 Kcal/kg.*

Diseases of turkeys

Turkeys are more susceptible to most avian diseases than chickens. They may be affected by both infectious and noninfectious diseases such as *Erysipelas, Histomoniasis, Mycoplasmosis, Newcastle disease, Turkey viral hepatitis, Lymphoid leucosis, Aspergillosis, Mycotoxicosis, Turkey coryza, Fowl cholera, Fowl pox, Haemorrhagic enteritis, Salmonellosis, Coccidiosis, predation, Ecto- and endo-parasitism.*

Production and Management of Ostriches

Ostriches are ratites, the name for a group of species of large flightless birds that include the *Emu, Rhea, Kiwi and Cossowary*. The ostrich is native to Africa with over five well known species such as **Red neck Sahara ostr**ich (*Struthio camelus camelus*), **Blue neck South African ostrich** (*Struthio camelus australis),* **Blue neck Somalian ostrich** *(Struthio camelus molypdophanes*), **Red neck Massai ostrich** (*Struthio camelus massaicus*) and **Red neck Mauritanian ostrich** (*Struthio camelus spatzi*). Ostriches reach sexual maturity at 2 to 3 years with both wild and domestic ostriches living up to 50 years. Ostriches will reproduce in either monogamous or polygamous situations with both the male and female incubating the eggs under natural condition which may last between 39 to 58 days. The breeding

season begins around June and lasts for 2 to 3 months with a female laying egg every day or every other day.

Brooding/care of ostrich chicks

The ostrich chicks should be taken to a brooding room with a supplemental temperature of 33^0C to 35^0C immediately after hatch because they cannot regulate their body temperature at this early stage. This temperature is reduced by 2 to 3^0C every 2 or 3 weeks until 16 weeks when supplemental heat is no longer required.

Housing and ostrich pen management

Ostriches are reared after brooding on a fenced range land with fencing reaching up to 5 feet high. A pair requires at least a quarter of an acre of land with an open shade to provide shelter during rain and protect the feed/water pans.

Feeds and feeding of ostriches.

The ostrich chicks are usually not fed for the first 5 to 6 days during which they depend on the large yolk reserve. However, chicks have the habit of eating anything in sight so, the litter material on which they will be reared should be placed as early as 3 days of age. At a younger age, chicks can be fed on starter/chick mash diet with 16 to 22% crude protein and high calcium to avoid leg abnormalities. Ostriches are referred to as avian herbivores hence, as they grow older, the birds should be allowed access to more forages and fibre diets to avoid impaction.

Diseases of ostriches

Ostriches are susceptible to the following diseases: *omphalitis, fading chick syndrome, leg abnormalities, stomach impaction, foreign body ingestion and ventriculitis, avian pox, Newcastle disease, avian influenza, salmonellosis, mycoplasmosis, colibacillosis, botulism, internal and external parasitism, helminthosis and predation*.

Breeder Farm and Hatchery Management

The breeder poultry farm produces fertile eggs for hatching from grand parent or parent stock.

Critical parameters and requirements in breeder farm management are *strict biosecurity, optimum temperature, good ventilation, relative humidity, lighting, vaccination and preventive healthcare, feeding and weight measurements to maintain uniformity, good waste management, hygienic egg collection, external parasites and rodent control*.

During rearing, male and female chicks should be reared separately for 20 – 22 weeks because of their different growth rate but later mixed together at 10% male to female ratio.

Hatchery management

Hatchery equipment

The hatchery equipment important for artificial incubation of eggs are:

a. ***Incubator:*** This may be a combine type incubator, having the setter and hatcher together in a single cabinet or a separate setter and hatcher.

b. ***Egg candler***: It is used for candling eggs in a dark room to visualize the internal condition of the eggs during incubation. Thereafter, any infertile eggs and or dead in shell eggs are discarded.
c. ***Setting and hatching trays:*** The setting tray allows for the turning of the eggs while the hatching trays do not.
d. ***Chick boxes***: These are used for packaging of chicks for delivery to poultry farmers.

Incubation Parameters

Incubation of eggs requires suitable parameters for success, and these are:

1) Temperature. 2) Humidity. 3) Ventilation. 4) Turning and Positioning. 5) Monitoring.

Summary

Poultry production is a very important sector of animal agriculture. Generally, exotic breeds are produced under intensive management system while the local breeds are reared extensively or semi-intensively. Successful poultry production starts with proper housing and efficient feeding management. Rearing other poultry species such as turkeys and ducks could be as profitable as chicken rearing because they are more resistance to diseases. Biosecurity and health care are imperative for a successful poultry enterprise.

Exercises

1. Explain the problems and prospects of poultry production in Nigeria.
2. Identify the advantages of the exotic breeds vis-a-vis the local breeds of chickens.
3. Give five reasons why brooding of chicks should be done within their first few weeks of life.
4. Explain the appropriate feeding management that can enable a farmer to achieve market weight in broilers at six weeks.
5. What are the indices for assessing the laying performance of exotic commercial layers?
6. What do you understand by the term biosecurity?

Further Studies

1. Process of egg synthesis in domestic fowl.
2. Management of heat stress in poultry production.
3. Chicken processing.
4. Poultry feed formulation.
5. Poultry feed additives such as Probiotics, Prebiotics and Symbiotics.

6. Artificial insemination in breeder stocks.

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Chapter 12B

Fish Production and Management

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Overview

Fish is regarded as a cheap source of animal protein and healthy nutrients like heart- friendly Omega 3 and 6 fatty acids. Sustainable exploitation of fishery resources contributes significantly to per-capita level of living and general wellbeing of the populace via improved food and nutrition security, increased income, improved livelihoods, and promotion of economic growth. Fish is produced either by capture or culture, and production by capture has reduced over the years due to over-fishing making this means of fish production unsustainable. Fish production in Nigeria comes from four major sources namely: importation, artisanal fishery, industrial fishery, and aquaculture. Aquaculture has grown steadily in recent times in Nigeria, with the country ranking as the highest producer of the African catfish in the world, and second only to Egypt in aquaculture production in Africa.

The aquaculture sub-sector is therefore considered a very viable alternative to meeting the nation's need for self-sufficiency in fish production, based on its high reliability in return on investment and low capital intensity relative to capture fisheries. Hence, it becomes pertinent to improve on fish production by culture to bridge the yawning gap between fish demand and supply in Nigeria.

Objectives

The objectives of this course are to:
1. identify the characteristics of culturable fish species;
2. describe aquaculture production processes;
3. explain fish spawning techniques;
4. demonstrate the management of fish hatchery; and
5. discuss the strategies for successful fish production.

Introduction

Why fish production and management?

As students of Veterinary Medicine, it is important to have a background knowledge of the fisheries and aquaculture industry in Nigeria. Fish supply in Nigeria, as in other countries of the world, is derived from three major sources, namely:

1. Capture fishery that comprise of

    I) Artisanal fishery (inland and coastal fishing)
    II) Industrial or trawl fishing

2. Culture fisheries commonly referred to as aquaculture or fish farming, and
3. Importation

Capture fishery comprises of fish hunted from open water bodies like rivers, lakes, reservoirs, dams and oceans by local fishermen, using simple fishing gears and craft (artisanal fishery) or by fish trawlers that employ fishing vessels on high seas (industrial fishery).

Aquaculture by definition is the farming/controlled rearing of aquatic organisms including finfish, shellfish, and aquatic plants in a receptacle called pond. The control involves human intervention in the areas of species selection, artificial breeding, pond design, stocking density, feeds and feeding, water quality management, disease prevention and control, marketing and sale of fish farm produce.

Overfishing has made capture fisheries unsustainable, unlike aquaculture where controlled propagation of culturable fish species, systematic rearing and harvesting ensures sustainability. This lecture focuses on the management of cultured fish.

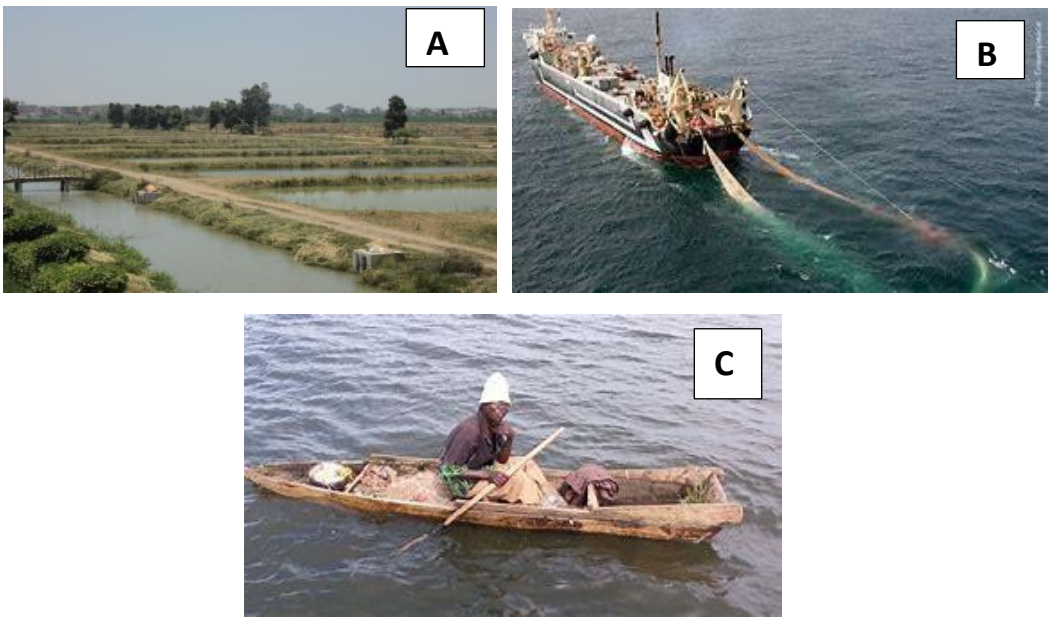

Figure 1: Fish culture using earthen ponds (a), Industrial fishing using fish trawler (b) and artisanal fishing using canoe (c).

Classification of Fish Culture

Fish production by culture can be classified based on intensity of production, number of fish species cultured in a facility and enterprise combination.

Classification by Intensity

Fish can be reared under i) **Extensive**, ii) **Semi-intensive** and iii) **Intensive** rearing systems. In the extensive rearing system, fish stocked in enclosures are allowed to grow on free range in ponds fertilized to produce natural food, but without application of supplementary diet nor proper monitoring for growth and survival. In the semi-intensive rearing system, moderate level of supplementary feeding is done in addition to pond fertilization for the development of natural food (plankton) in the ponds. Intensive rearing ensures adequate provision of good quality diet on a regular basis, monitoring of growth, health and survival of the fish as well as the quality of the water in which the fish are reared. Fish stocking density is also higher under intensive rearing.

Figure 2: Fish culture under intensive rearing system (A), under semi-intensive, poultry-cum-fish integration (B) and under semi-intensive rice-cum-fish integration (C).

Note the high density of fish in the intensive system.

Classification based on the number of species.

Single species of fish can be reared in a facility in the monoculture system of rearing. Rearing of multiple species in a polyculture system is however done to take advantage of the diverse feeding niches in ponds (especially earthen), or the use of a predator fish like the catfish to control the population of a prolific breeder like tilapia, while benefiting from the abundance of natural food presented by the numerous baby tilapia.

Classification based on enterprise combination.

Fish production by farming can be integrated with crops or animals in a vertical or horizontal version. Vertical integration is when the crop is grown directly inside fish ponds (earthen) as with rice-cum-fish integration, or the animal pen is constructed directly on top of the fish pond, in which case, the animal manure drops directly into the pond to fertilize the water for natural bloom of algae and zooplankton (poultry/piggery-cum-fish integration). On the other hand, in horizontal integration, the fish pond is located near the crop farm or animal pen and manure from the animals are transferred manually to the ponds, or organically rich pond water used to irrigate the crop farm manually.

Species Selection for Culture

Not all fish are culturable. Fish species suitable for culture must have attributes that make the culture feasible, viable and profitable. Such attributes are as follows:

Reproduction in captivity, production of numerous and hardy eggs, adaptability to culture systems, adaptability to polyculture, rapid growth to large size, acceptance of artificial feed, tolerance to high density, high survivability, easy to handle, harvest and transport, high pathogen resistance, controllable cannibalistic or territorial tendencies, ready

availability of seeds and breeders, high market demand / consumer acceptability, good feed conversion efficiency, ease of processing with good dress-out weight value and long shelf life. The growth of the aquaculture sector in Nigeria has largely been linked to the significant growth in catfish production. Data from the Federal Department of Fisheries show that production of catfish (*Clarias gariepinus*, *Heterobranchus* spp. and *Clarias* hybrid) ranged from 21,372 metric tons in 2001 to 253,898 metric tons in 2012 (AU-IBAR, 2014). Out of this quantity, *Clarias gariepinus* alone was 228,508 metric tons (90.1%). Aquaculture production in Nigeria has grown by 12 percent a year from a little over 6,000 metric tons in 1980 to nearly 307,000 metric tons in 2016. The culture of some other indigenous and foreign species like Tilapia and Pangasius are also gaining ground in Nigerian aquaculture.

The species used in fish culture in Nigeria, based on the possession of a good number of these attributes, are as listed in Table 1 below:

Table 1: Fin-fish species used for commercial culture in Nigeria

Species	**Common name**	**Species**	**Common name**
Clarias gariepinus	Mud-catfish	*Lutjanus gorensis*	Gorean Snapper
Clarias angularis	Mud-catfish	*Oreochromis niloticus*	Nile Tilapia
Heterobranchus longifilis	African catfish	*Chrysichtyhs nigrodigitatus*	Silver catfish
Heterobranchus bidorsalis	African catfish	*Heterotis niloticus*	African bony tongue
Citharinus citharus	Moon fish	*Channa obscrura*	Snake head
Gymnarchus niloticus	Trunk fish	*Cyprinus carpio*	Common carp

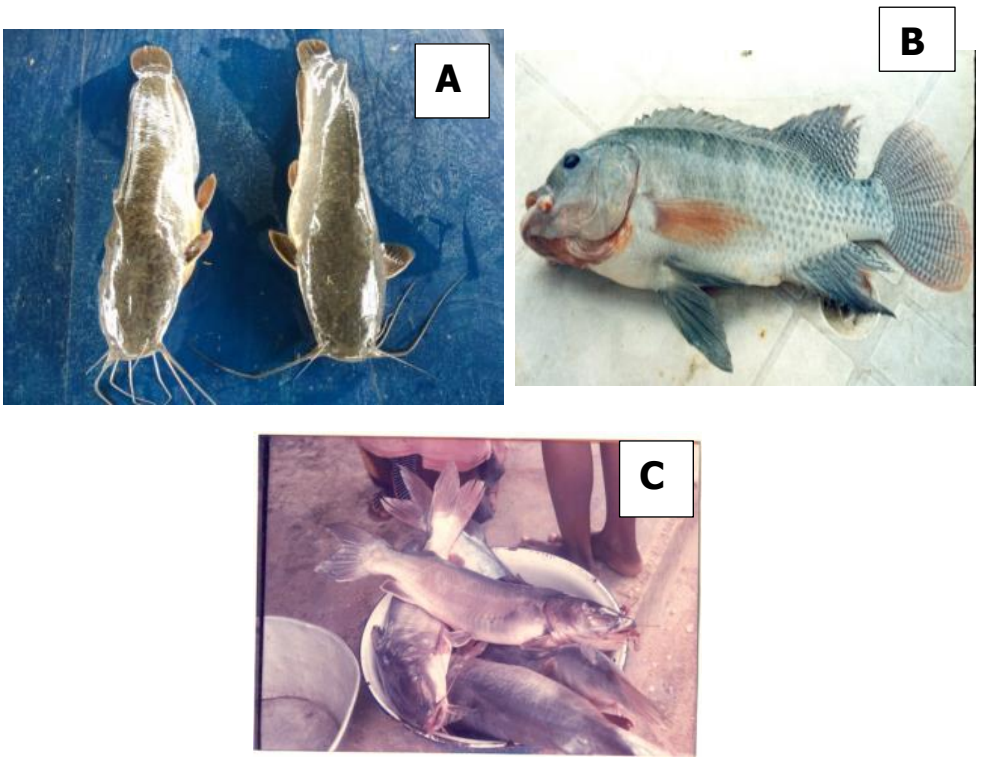

Figure 3: African catfish species (A), Tilapia (B) and Silver catfish (C).

Apart from fin-fish, there are other shell-fish that are farmed commercially (Table 2). They include the following:

Table 2: Shell-fish species used for commercial culture in Nigeria

Family	**Species**	**Common name**
Penaeidae	*Penaeus monodon*	Tiger Shrimp
	Penaeus notialis	Pink Shrimp
Palaemonidae	*Macrobrachium vollenhovenii*	African river prawn
	M. macrobrachion	Brackish water prawn
	Palaemonetes atlantica	Creek shrimp
Cardiidae	*Crassotrea gasar*	Mangrove oyster

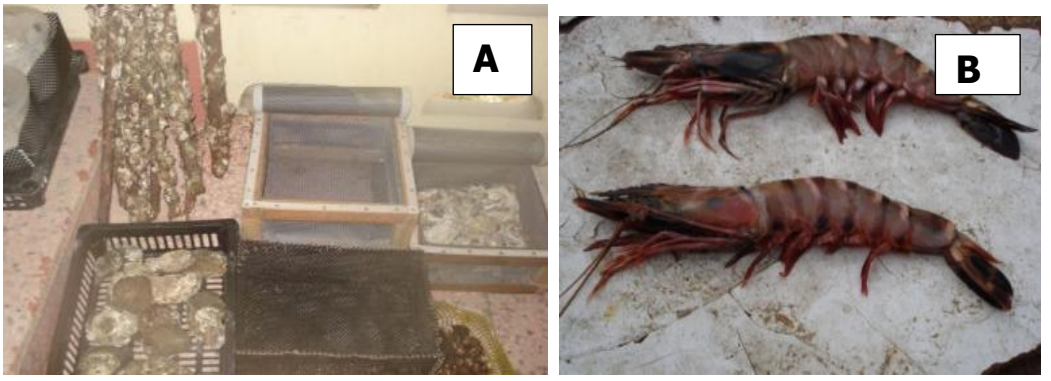

Figure 4: Oysters on rafts and trays A) and Tiger shrimps (B).

Aquaculture production processes

There are three major processes involved in aquaculture production and they are as follows: 1) Brood-stock development, 2) Seed propagation or fingerling production and 3) Grow-out or table fish production.

Brood-stock development

Fish brood-stock are the sexually matured male and female adult fish reared, reserved, and selected for breeding purposes. They can be selected from the harvested table fish (top 10% best performers) and further reared for one year or more depending on the age at maturity of the species. Stock can be selected from the wild but must be healthy and matured. The source of brood fish must be known and reputable for the purpose of traceability. Brood-stock are kept in ponds at low stocking density (usually $1/m^3$) and fed twice daily with high quality fish feed (≥ 40% crude protein) at a feeding rate of 1- 2% body weight daily. Good water quality must be maintained in their holding facility to ensure good health condition and gamete viability.

Seed propagation

Seed propagation entails the production of offsprings or young ones from the brood-stock to ensure the continuation of the species from one generation to another. It is very important in aquaculture as the source of seed for the stocking of rearing facilities. Seeds can be recruited from the wild although this method of seed procurement is not reliable. Hence, artificial seed propagation techniques become very important for regular and adequate seed supply. Fish seeds produced for commercial purpose are:

1) Fry (free swimming small fish between 0.1 - 0.5g)
2) Fingerlings (finger-sized fish of 1g)
3) Post-fingerling (finger-sized fish between 3-5g) and

4) Post-fingerling / Juvenile (advanced stages of fingerlings between 8 - 10g)

Methods of seed propagation

There are two major methods of fish seed production:
Natural Breeding: Fish spawn naturally in ponds or tanks after attaining sexual maturity. Hormonal induction is not necessary. This is

the mode of seed production in some fish species like Tilapia, Heterotis, Megalops and Gymnarchus, when environmental conditions favour reproduction. Natural spawning occurs during the rainy season with the inundation of the grassy banks of ponds or an increase in water level.

Artificial Breeding: This is carried out when the brood-stock are sexually matured but requires hormonal induction to spawn. Fish can be hormonally induced and allowed to spawn on their own (induced natural spawning). On the other hand, following hormonal induction and ovulation, eggs can be stripped out of the female, and artificially fertilized with milt (sperm) that has also been stripped or dissected from the male (dry stripping method). The dry stripping is practiced mostly in the clariid catfish species and can be achieved by injection of natural or synthetic hormones. The fish pituitary gland, located beneath the brain in a bony structure called sella tursica, is the commonly used source of natural hormone. The pituitary gland can be extracted from fish of similar size as brood-fish, ground in saline, in ceramic or plastic mortar and pestle, and injected immediately. In the alternative, it can be dried in acetone, powdered and stored for future use. Carp and catfish pituitary glands are commercially available. Dried carp pituitary powder is injected at a dosage of 4mg/kg of female.

There are different types of synthetic hormones in use to achieve ovulation in fish. They include Human chorionic gonadotropin (HCG), Lutenizing hormone-releasing hormone analog (LHRHa) and Ovaprim®. Ovaprim® is the most commonly used hormone available in liquid form (ready to use) and requires no special storage. The dosage is 0.5ml/kg of female spawner.

Incubation, Hatching and Fry Rearing

Stripped eggs are mixed with extracted milt (semen) and fertilization is activated by addition of water. Fertilized eggs are incubated by spreading in monolayer on framed or unframed net, or kakaban under running and aerated water in concrete tanks, fibre glass troughs, glass troughs, jars, trays or boxes. Hatched larvae drop through the mesh

while the unhatched eggs are retained on the net or kakaban for ease of removal and to avoid pollution. Fertilized eggs hatch in 18 – 30 hours after fertilization at a water temperature of about 27 - 30^{o}C. Water temperature below 24^{o}C may result in low hatching rates. Dead eggs during incubation will become whitish in colour and should be siphoned out of the incubation system to avoid pollution as well as fungal and bacterial infection. The larvae remain in the incubation unit for 3 – 4 days (depending on water temperature) until their yolk is fully absorbed. The yolk-sac fry is not fed.

From about day 3 or 4 post-hatch, fish larvae could be fed with artemia which has about 54% crude protein level. This could be given to fish for about 6 to 7 times a day till day 7 post-hatch, and towards the end of this stage, 0.2 mm extruded fish diet can be introduced for another 7 days. From day 14 of age, the 0.3 – 0.5 mm diet (which could have about 58% crude protein and 12% fat) is fed to the fry, up to day 30 (0.7-1.0 g fish size) when the 1.0 mm crumbs are introduced. From here, the fingerlings can be further reared to fingerlings (3-5 g) or juveniles (8-10 g) in nursery tanks/ponds before stocking in grow-out ponds for table-fish production. Good water quality is paramount for successful fry rearing. The desirable levels of some of the water quality parameters are:

Temperature, 28^{o} C– 30^{o} C; Dissolved oxygen, ≥ 3mg/l; pH, 6.5 – 8.5; Ammonia, < 0.1mg/l and and Nitrite, < 0.05mg/l.
A clean and hygienic environment will reduce the risk of infection. Waste products must be regularly siphoned out of culture facility to prevent fouling of water. Fry and fingerlings must be protected from predators and vermin. From the fry stage, fish must be graded and separated into different sizes to avoid cannibalism. Fish must be fed appropriate diet and pellet size as they grow.

Table-fish Production

When farmers buy catfish juveniles from hatcheries, they often start them on 2mm sized floating feed. Routine sampling of fish in the ponds is done once in two weeks to check the average body weight of the fish and determine the quantity of feed to give them (see Table 3). The records of the weights from the sampling and records of feed consumed by fish in the last 2 weeks are used in calculating the feed conversion ratio (FCR) as shown:

$$\frac{\text{Weight of fish feed consumed in last 2 weeks in kg}}{\text{Increase in body weight within the 2 weeks in kg}}$$

Table 3: Guide for feeding fish

Feed size (mm)	Fish size (grams)	Feeding level (% food of body weight/day.	Feeding level (kg feed /1,000 fish/day)
0.9-1.3	1-2	12.0 -15.0	0.15-0.24
1.3 -1.8	2-5	9.5 -12.0	0.24-0.48
2	5-10	7.5 -9.5	0.48-0.75
2	10-30	5.5-7.5	0.75-1.7
3	30-50	4.5-5.5	1.7- 2.3
3	50-70	4.0-4.5	2.3 -2.8
4.5	70-100	3.5-4.0	2.8-3.5
4.5	100-200	3.0-3.5	3.5 – 6
6	200-300	2.6-3.0	6 - 7.8
6	300-400	2.3-2.6	7.8 -9.2
6	400-500	2.1-2.3	9.2-10.5
6	500-600	1.9-2.1	10.5-11.4
6	600-800	1.6-1.9	11.4- 12.8
6	800-1000	1.4-1.6	12.8 -14
6	1000-1500	1.2-1.4	14 – 18

In calculating the total body weight of fish, the average weight will be multiplied by the population of fishes still alive. This implies that

wastage of feed and high mortality can affect the FCR. For good performance of catfish, cumulative FCR should be between 1.1 and 1.2. The lower the FCR value, the better the performance. For Nile tilapia (*Oreochromis niloticus*), a cumulative FCR of 1.5 to 2.0 has been reported (Ogunbona, 2012). For an animal to have a cumulative FCR of 1.2, it means for every 1.2 kg of feed cumulatively consumed, the animal gained 1 kg of flesh.

In a bid to reduce the cost of production, some farmers switch over from using floating pelletized feed to well formulated sinking feed once their fish are up to 250g average body weight. Fish must be provided with good quality diet in the right quantity on a daily basis using correct feed size and feeding rate. Feed must be balanced, with crude protein level of 40 – 45% for catfish and 28 -30% for tilapia.

Table 4: Breakdown of cost of feeding 1,000 catfish from juveniles to table-size

Period post-stocking of juvenile catfish	**Feed type(floating) and pellet size**	**Quantity of feed needed per month for 1000 catfishes**	**Cost per kg**	**Cost per 15 kg**	**Cost of feed per month**
Weeks 1 to 4	2mm	60.58 kg	N843.3	N12,650	N51,087
Weeks 5 to 8	3mm	107.56 kg	N783.3	N11,750	N84,252
Weeks 9 to 12	4mm	212 kg	N770	N11,550	N163,240
Weeks 13 to 16	6mm	232 kg	N743.3	N11,150	N172,445
Weeks 17 to 20	6mm	232 kg	N743.3	N11,150	N172,445
Weeks 21 to 24	6mm	258 kg	N743.3	N11,150	N191,771
		1,102.08kg			
			Total cost of feed		**N835,240**

Exercise: Given that the set of fish above had a livability of 95% at 24 weeks and average weight of 970 g, initial weight at stocking as 8g and cost of live catfish as N1,800/kg, what is the gross profit after sales of this batch of fish? What is the cumulative FCR in 24 weeks ?

95% livability =1000 x 0.95 = 950 live catfishes.
Total body weight= 950 x (970-8 g)
= 950 x 962 = 913,900g or 913.9 kg
Income from sale= 913.9 x 1800 = N1,645,020
Cost of feed = N 835,240
Gross profit =N 809,780

Cumulative FCR= 1,102.08kg of feed ÷ 913.9 kg body weight = **1.206**

From gross profit, one can deduct the cost of purchasing juveniles. If it costs N150,000 to construct the pond that will be used for 2 cycles per year and expected to last for 5 years (10 cycles), this means an additional deduction of N15,000 per cycle. Other deductions could include 6 months' salaries, electricity bill, cost of plumbing works and purchase of pumping machine, etc. For a bigger farm with more ponds that require use of good borehole water, the cost of sinking boreholes is divided over the number of cycles (2) per year (5) and number of ponds.

Disease Prevention and Control

One of the main duties of veterinarians is disease prevention and control in animals, including aquatic animals like fish. Disease occurs when there is a deviation from the normal structure and function of the organs in the fish. Diseases could be infectious or non-infectious. Infectious agents causing diseases are bacteria, fungi, parasites and viruses. According to Ikpi and Offem (2010), bacterial diseases are amongst the most common diseases affecting fish. Amongst the reported species of bacteria that have caused outbreaks in fish farms in Nigeria are *Bacillus* spp. (Oladosu *et al*., 1994), *Staphylococcus aureus* (Oladele *et al*., 2012), *Aeromonas sobria* (Oladele *et al*., 2011),

Acinetobacter baumanni (Oladele *et al.,* 2010a) and *Klebsiella pneumonia* in catfish fry (Oladele *et al.,* 2010b). Non-infectious conditions could be associated with environmental problems like ammonia and nitrite toxicities (Oladele *et al.,* 2021).
Disease prevention is done by ensuring strict adherence to bio-security measures such as those stated below.

1. Sanitation: This entails the disinfection of culture facilities, utensils, materials (e.g., water, nets, etc.), personnel and vehicles through irradiation (ultra-violet irradiation) and or chemical (formaldehyde, chlorine, salt, etc.) means. This will include the provision of foot-dips at the entrance of the farm and fish hatchery.
2. Quarantine of new fish entrants to farms.
3. Restriction of fish movement.
4. Ensuring safe water source and good water quality.
5. Screening of culture facilities with net against birds and other predators.
6. Prompt removal and safe disposal of dead fish from culture facility.

Record Keeping

There is a need to maintain accurate records of all farm activities (feeding, water parameters, purchases, sales, visitors, etc.). This is important in tracking developments.

Records should be kept either in hard or soft copies or in both forms and should be inspected at the beginning and the end of each day.

Summary

Fish production is a major source of animal protein and a very profitable venture. There are three sources of fish production, but fish culture is the most sustainable. Culturable fish species can be reared extensively, semi-intensively or intensively. Careful selection of the brood stock and efficient propagation are crucial in fish farming. Artificial breeding technique as well as fry and fingerling management guarantees sustainable operation. Control of diseases and predators based on

adherence to strict biosecurity is vital to good production. Good record keeping is essential, and part of good management practice.

Exercises

1. Why do we farm fish?
2. State the sources of fish production and their various advantages.
3. Identify five culturable fish species indicating their special qualities.
4. Classify fish culture using three different criteria.
5. Briefly explain a standard spawning technique.
6. State four biosecurity measures used in disease prevention.

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Chapter 13

VHM 204: Animal Welfare

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Overview

Animal welfare refers to the physical and mental state of an animal in relation to the conditions in which it lives and dies. It is a complex and multifaceted subject having ethical, scientific, economic, social, cultural, religious, and political aspects. This course introduces the subject of animal welfare to Doctor of Veterinary Medicine (DVM) students at the 200 level to guide their understanding of feelings and ethical issues concerning the welfare of animals while in training and as graduate Veterinarians. The course covers aspects of ethical, legal and regulatory framework for animal welfare including the right to kill, animal population dynamics in relation to animal welfare, humane transportation, killing, disposal and harvesting, care of animals during disaster as well as animal freedom and behaviour. Also, animal care in research including international standards and best practices in research and training are covered.

Objectives

The objectives of this course are to:

1. describe the ethical, legal and regulatory framework for animal welfare and animal euthanasia;
2. demonstrate social responsibility for animal well-being and reducing animal suffering;

3. determine the effective measures to apply when adverse events occur in animals; and
4. present the best practices for animal use in research.

Introduction

Human knowledge of animals, particularly their sentience, needs, and natures, is always expanding. Physical conditions depicting poor welfare are easier to access and comprehend particularly for veterinarians, who undertook much of the early work on welfare. Nonetheless, fresh study inevitably results in a better grasp of mental conditions, requirements, and natures. This is especially true for ethological studies such as "preference testing," which measures and evaluates the preferences of animals.

This may be the reason why older definitions of well-being focused primarily on physical conditions as opposed to more recent definitions which have recognized the intricate, nuanced nature of animal care.

While not opposed to the usage of animals, animal welfare refers to the desire to ensure adequate living conditions and a humane end to an animal's existence. The term "animal rights" refers to the philosophical idea that all animals should have certain rights, notably the freedom from meddling and death caused by humans. Animal rights activists disagree philosophically with human usage of animals, although some do allow "symbiotic" interactions such as owning a pet.

The main distinction between conservation and animal welfare is that the former is concerned with species (and their extinction), whilst the latter is concerned with each animal (and its suffering). Animal welfare advocates think that every animal has intrinsic worth and ought to be revered and safeguarded. They hold the notion that animals should be allowed to live their lives free from avoidable suffering at the hands of people since they are conscious of the biologically determined impulses, interests, and natures that they possess as well as the capacity to feel pain and suffer.

The reason that the environmental movement has garnered more support than the animal welfare movement is not difficult to understand. More empathy and altruism are needed for animal care

than for conservation. Human-centered goals, such as not wanting a species to become extinct because of the loss to future generations, can motivate conservation efforts by humans.
Although many people are now aware that animals experience pain and suffering, they do not prioritize acting in this area because it could potentially disrupt their way of life and behaviours. Welfare goes beyond simply being free from cruelty or unnecessary suffering. It is a lot more intricate. It encompasses the following various states:

Definition Based on Physical States
McGlone (1993) contends that an animal is only in a bad condition of welfare when its physiological systems are upset to the extent that its chances of surviving or reproducing are compromised. According to Fraser and Broom (1997), an animal's state as it relates to its efforts to adapt to its environment is defined by its welfare. Welfare is only low when a physical condition makes it difficult for people to survive or reproduce (McGlone, 1993).

Definition Based on Mental Health
Welfare is significantly impacted by mental health. Scientists among others are learning more about and exploring these states. To conclude that an animal enjoyed good welfare, neither health nor lack of stress nor fitness is necessary and/or sufficient. The welfare of animals depends on their feelings (Duncan, 1993).

Definition Based on Naturalness
The animal's capacity to satisfy its basic needs and desires is referred to as its third condition or naturalness. Its welfare is harmed by this frustration. Recently, this third dimension has been acknowledged and included. Well-being entails nurturing and completing the telos of an animal, in addition to controlling pain and suffering (Rollin, 1995).
The concept of animal welfare is frequently contested. However, these three states which are listed in the definition provided by the World Society for the Protection of Animals (WSPA) in its veterinary training

resource titled "Concepts of Animal Welfare," offer the most comprehensive to date.

Legal Framework for Animal Welfare

Pre-Colonial Period

Before the advent of the colonial masters, the animal welfare act was under the chiefs or the head of communities. The act/charter varied from one community to another, but it could be seen in various forms of adages from the three major tribes in Nigeria.

For example, in Yorubaland, an adage states that for ease of both dog and wild animals, the hunters and farmers hunt in the forest and open grassland during the dry season. This naturally means that hunting expedition is not taken as an all-year affair but limited to a particular period in a year. If not so, the population of the fauna would have been irreparably depleted. This may be the guiding factor for present-day open and closed seasons which is for breeding and hunting to avoid depletion leading to the extinction of some of the game animals.

Other adages include when an animal is shot and runs away, it must be traced so that it will not become maggot meat, meaning that a shot animal must not be abandoned to wriggle in pain (discomfort) and be wasted. A dog whose owner is known is never beaten, signifies prevention of cruelty to animals to avoid negative consequences. An egg-eater does not feel the hen's vent pain, indicating the necessity to avoid the abuse of animals. Yorubas also believes that vultures can never be killed either for meat or to appease the gods which takes vultures completely out of the use of human beings. Hence, their presence everywhere one goes. The same goes for a snake, that one does not collect snake eggs, and whosoever does, and the eggs touch one another, it is believed that the female snake will hear the sound and go to look for those eggs in anger. In addition, some families regard some of the animals (Crocodiles, African Giant Rat, Snakes, Tortoise, etc.) as deities. Hence, they will go all out to preserve such animals, thereby extending their life span and encouraging their productivity.

The Hausas have a saying that each person prefers a domestic animal which he keeps, yet a neighbour to a goat rearer does not rear a wolf

due to the danger inherent in the proximity of the two animals. This gives a clear example of the mutual responsibility of the owners of animals to cater for their animals, so they do not become a nuisance or otherwise to society. It is also generally believed that a donkey cannot rest with a heavy load on it; this belief highlights humane treatment for all categories of animals especially those used as beasts of burden/transportation. Those animals should be allowed to rest without any form of stress or pain. Others include the Yoruba saying that a lost dog is the one that did not listen to its owner. This is well rooted in the fact that human beings care for their animals and provide for them in all areas.

The Igbos have a saying that a cow is too big for casual roasting. The reason for this is to consider the size of the animal before slaughtering and not just kill any animal for frivolities. Attention should be paid to small animals on such occasions. This will conserve the big animal for a greater occasion and allow them to rest because of the length of their gestation period.

Post-Colonial Era

It is important to note that various legislation on animal welfare/rights in 1900 in Britain were also applied in Nigeria through the Statute of General Application. It is enough to state here that those laws were applicable in Nigeria because they satisfied the two criteria laid down for the applicability of the statute of general application in Nigeria. The two criteria are: by what court is the statute applied in Britain and to what classes of community does it apply?

Animal Welfare Policy and Legislation

Currently in Nigeria, animal welfare issues are provided for under several Acts of Parliament and these include The Prevention of Cruelty to Animals Act, Section 495 Criminal Code; Animal Diseases Control Act, 1988; Wild Animal Law 1965; The Dog Act, 1943; The Dog Law, 1963; and The Veterinary Surgeons Act, 1952/53. The Nigeria constitution holds that any person who:

1. Cruelly beats, kicks, ill-treats, over-rides, over-drives, over-loads, tortures, infuriates or terrifies any animal or causes or procures or being the owner, permits any animal to be so used.
2. Unreasonably does or omits to do any act or causing or procuring the commission or omission of any act, causes any unnecessary suffering, or, being the owner, permits any unnecessary suffering to be caused to any animal.
3. Conveys, carries, or being the owner permits animals to be conveyed or carried in such manner or position as to cause such animals unnecessary suffering.
4. Willfully without any reasonable cause or excuse administers, causes, procures or being the owner, permits such administration of any poisonous or injurious drug or substance to any animal or willfully without any reasonable cause or excuse causes any such substance to be taken by any animal.
5. Subjects or causes or procures or being the owner permits animals to be subjected to any operation which is performed without due care and humanity.
6. Causes or procures, or assists at the fighting or baiting of any animal, or keeps, uses, manages, or acts or assists in the management of any premises or place for the purpose, or partly for the purpose, of fighting or baiting any animal, or permits any place to be so kept, managed or used, or receives or causes or procures any person to receive money for the admission of any person to such premises or place is guilty of an offence of cruelty and is liable to imprisonment for six months or to a fine of fifty naira, or both such imprisonment and fine (COFRN, 1999).
The purpose of animal welfare laws is to enhance animal well-being, namely by establishing a minimum threshold for acceptable conditions. It might be possible to accomplish the objective in a more adaptable way by introducing some of the strategies and concepts created within welfare evaluation.

Laws of the Federation of Nigeria
Animal Diseases (Control) Act Arrangement of Sections
Sections

There are other regulations governing animal welfare in other countries and some of them include regulations on the breeding of animals.

Needs

As needs are the items that should be provided to ensure an animal's welfare, the term "needs" is frequently used in discussions on welfare. The definition of a need is: "A requirement, fundamental to the animal's biology, to obtain a specific resource or respond to a specific

environmental or bodily stimulus." Needs can cover a wide range of necessities like food, drink, comfort (either during transportation, slaughtering, harvesting and care during a disaster), avoiding contagious diseases, and access to a stimulating/scintillating environment. It is our moral duty as humans to meet the needs of animals in our care. Animals place varying amounts of attention on certain needs. Effects following the elimination of needs give insight into their relative importance.

Sentience

The 'sentience' of animals is now widely acknowledged, which emphasizes the importance of preserving welfare. Animals have been formally recognized by the European Union as "Sentient Beings" (1997). Sentience means that: - They have the following characteristics: They are aware of their immediate environment; they have an emotional component; they are aware of what is happening to them; they can learn from experience; they are aware of body sensations such as pain, hunger, heat, and cold; and they are aware of their interactions with other animals. They can select from a variety of creatures, things, and circumstances.

Animal Welfare Assessment

There is an increasing amount of research being carried out on animal welfare as it has become a science in itself. Governments, businesses, trade associations, welfare organizations, and other organizations are funding this research. It frequently serves as the foundation for changes to animal protection laws. Additionally, it is utilized to enhance living conditions for animals raised for food, used for research, held in captivity, or kept as pets. For a welfare assessment, the following three factors are crucial: Utilizing the Five Freedoms as a framework, evaluating the inputs and outputs on well-being, and quantifying the issue using the severity, duration, and number of animals impacted. The variables that impact welfare are inputs. The effects of these factors on welfare are known as the outputs.

Three examples of welfare inputs are as follows: **Environment**: housing, bedding, high-quality food, and water availability. **Stockman**: empathy, knowledge, and observational abilities. **Animal**: appropriate breed, age, and sex for the system. Heart rate, respiration rate, adrenal habituation, blood pressure, catecholamines (adrenaline and noradrenaline), enzymes, and metabolites are a few examples of physiological indicators of well-being. Welfare measures should, however, only be used sparingly. Welfare science is one of the various "components" of welfare mentioned in the World Society for Protection of Animals (WPSA)'s "Concepts of Animal Welfare," along with animal ethics and welfare law. It is debatable if the law is anything more than the socially approved practical application of the state of science and ethics as acknowledged by citizens and (ultimately) politicians. However, the crucial thing to remember is that there are other, less obvious criteria for assessing welfare in addition to science. Therefore, it is crucial to follow the "precautionary principle," and when in doubt, the action should always favour the well-being of the animals.

Welfare and Death

An animal's 'quality' of life is referred to as its welfare. Death, however, has an impact on the 'quantity' of animal life. Both, though, might be the subjects of ethical concern for people. The way an animal dies, such as the technique of killing, matters for its welfare. Furthermore, high death rates may be a sign of inadequate welfare conditions because these can lead to disease and death, as can production demands and overwork.

When an animal is stated to be stressed, what it typically means is that it is experiencing negative effects from its environment, either directly or indirectly. The term "stress" has however, been used in a confusing variety of ways. Because of this, some scientists have only used it once. Activity in the hypothalamic-pituitary-adrenal cortex (HPA) is a physiological response mechanism. Given that the HPA axis is momentarily elevated during courtship, mating, active prey capture, and active social contact, equating stress with increased HPA axis activity makes the term "HPA axis activity" redundant and is not

consistent with usage. Additional responses to obstacles are possible. Another definition of stress compares it with stimulation, but if environmental influences on an organism are generally referred to as stress, the term is once again meaningless. Most people would never refer to positive stimuli as stressors. An individual's control systems are overworked by stress, which has negative effects and eventually leadsto decreased fitness. Strain is a phrase that refers to reactions to stress and its immediate effects. The genes of that person would affect future generations when coping is impossible and failure to deal with results in decreased fitness.

Differences between animal welfare advocates and animal rights advocates

Animal rights advocates believe that animals have the same rights as humans and have turned themselves largely to vegetarians, not eating meat at all and some have gone to the extreme of not eating animal products such as eggs, milk, etc.

Animal welfare advocates	**Animal rights advocates**
Judicious use of animals for human benefit is morally right.	Using animals for human benefit is morally wrong.
Human interests always come first before animal interests.	Human interests should not overrule animal interests.
Humans should not cause animals unnecessary pain or death.	Humans should not cause pain or death at all in animals.
Treat animals as humanely as conveniently possible.	Treat animals humanely always and eliminate human made causes of animal suffering.
Humane euthanasia/killing of animals.	No killing of animals.

Objects to cruel practices such as dog fighting, confinement of veal calves, and pregnant sows.	Abolish the use of animals in any form; it is exploitation.

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Five Freedoms of Animal Welfare

The UK's Farm Animal Welfare Council (FAWC), which created the "five freedoms," offers insightful advice on animal care. They are now accepted on a global scale and have undergone some modifications. Currently, this takes the following forms:

Freedom from hunger and thirst: ready access to water and a diet to maintain health and vigour – this should be in the form of clean and affordable water, ditto for feed. It is also in terms of quality and quantity supplied to the animal. The feed must be balanced to supply all the nutrients to the animals. It must be kept in a cool dry place to avoid contamination from rodents and other vermin. It must also be tested not to have mycotoxin contaminants.

Freedom from discomfort by providing an appropriate environment, including shelter and a comfortable resting area – adequate spacing for the animals in their shelters, avoiding overcrowding. Do not mix animals of different ages and sizes, ensure the smooth running of the pen, barn or pigsty and remove anything that can scare the animals. This also involves humane transportation, humane slaughtering/killing, humane disposal of carcasses and care during a disaster.

Freedom from pain, injury, and disease by prevention or rapid diagnosis and treatment, adequate vaccination, medication, biosecurity, good hygiene, removal of sharp objects that can cause injury, dehorning, disbudding to avoid in-fighting and bullying, adequate spacing, normal mixing of age mate, teeth clipping, tail docking, etc.

Freedom to express normal behaviour by providing enough space, appropriate amenities, and the company of the animal's kind, room for exercise, environmental enrichment, allowing mild hunting in confinement for carnivores.

Freedom from anxiety and worry through ensuring that animals receive care that prevents mental anguish.

The Five Freedoms may intersect with one another. For instance, it is a natural behaviour for an animal to seek out food when it is hungry and consume it. An animal may become upset if it cannot obtain food or if its surroundings prevent it from engaging in typical foraging behaviour. Animals may therefore not be free from anguish if they are not free from hunger and are unable to show regular behaviour. Since death is the inevitable conclusion of all existence, no organism can be spared from it, but most of the livestock being reared are killed.
It is an ethical question whether we should kill animals. For many cultures, it has ethical worth to prevent animal deaths. Additionally, from the perspective of the animal, creatures have the desire to live and will typically try to avoid dying. Even if we are unable to guarantee that any animal will be spared from death, how an animal passes away does have an impact on animal welfare. A chameleon kept as a pet, for instance, would perish from hunger and related ailments if it is not fed appropriately. In that situation, a few of the Five Freedoms have been violated, which results in the animal's death.
The welfare spectrum includes "Poor," "Adequate," and "Good." At the 'Poor' end, the environment is such that the animal encounters primarily bad events and ongoing suffering, making its life unappealing. Animal well-being may be "Adequate" with better care and living conditions: the animal may encounter a few happy experiences but also a few negative ones. That is regarded as a worthwhile life. At the other end of the spectrum, welfare is "Good," meaning the animal experiences mostly pleasant things rather than just a lack of bad ones. This may be debatable anywhere in the world, but research can be conducted to ascertain the degree to be used. However, for the veterinarian in practice, it is important to evaluate aspects of welfare and then decide how good or awful they are in relation to similar circumstances or the scenario as it was previously.
The following should be calculated for each freedom: • the proportion of animals impacted (e.g., by hunger, thirst, fear, etc.); • the severity

of the condition (e.g., the proportion of moribund individuals against those with minor clinical symptoms versus those in good health); • the length of time the compromise has lasted.

Animal Welfare in Research

Irrespective of the animals involved in research, the following list (although not exhaustive) provides indicators for good animal welfare just as we have in the five freedoms.

Environment/Location.
Sanitation/Hygiene standards.
Surgical Procedures/Anaesthesia.
Post-surgical care.
Housing.
Caging.
Feed and water.
Animal handling.
Animal care and well-being.
Veterinary care.
Cage records/Case history.
Animal monitoring/Duty rosters/Public Holidays/Weekends/After hours.
Emergency/Contingency plans.
Transport facilities/Methods/Emergency kit.
Staff training and expertise.
Relevant/Existing Standard Operating Procedures/Work Instructions.
Biohazards/Noxious substances/Ionizing radiation/Chemicals.
Quarantine animals.
Escaped animals.
Animal Facility – authorized and controlled access.
Photographic or video evidence.

Alternatives in Research (Concept of 3 Rs)

The **3 Rs** are widely acceptable ethical frameworks for conducting scientific experiments using animals humanely. The principle was first introduced in 1959 by Russell and Burch in their book - ”The principles

of humane experimental techniques". The 3 Rs are stated and defined as follows:

Replacement: this is finding alternatives other than animals. If alternative approaches can provide the data needed or accomplish the same scientific goals, researchers should make every effort to avoid using laboratory animals. It involves the use of non-animal models, computer modelling, non-invasive imaging studies, established cell lines, animal cell tissues, abattoir materials, embryos, etc. This will reduce cost and minimize stress on experimental animals.

Reduction: this method has to do with decrease in the number of animals to be used for any research. It allows researchers to obtain information/results from fewer animals to achieve the same purpose in research. The use of animals will be kept to a minimum by design to attain only the level of statistical power required to accomplish the experiment's goals. It may mean that the number of experimental groups will be reduced or reduce the entire population. This will also minimize stress on the research animals, reduce the cost of research and, if well planned, could even yield more results.

Refinement: this is a method used by researchers in situations where the use of animals is inevitable in research. It includes methods to improve the husbandry of animals, and scientific procedures to minimize actual or potential pains or distress experienced by the research animals. This refinement of the experimental methodology can be done using procedures to reduce or eliminate potential pain, suffering, or distress and improve animal welfare. When this cannot be avoided, to counteract those effects using ataractics (tranquillizers), neuroleptics (dissociative agents), anaesthetics, analgesics, and other efficient strategies.

The above procedures will not permit the killing of animals for pointless, unreasonable, unjustifiable, or improper causes, or the use of animals for research. Also, they keep animals free from disease, parasitism, injury, and pain through prevention, rapid diagnosis, and treatment. Permit animals to express normal behaviour by providing as much space, appropriate facilities in which to live, and in the company of the

animal's kind, acknowledging the inherently social nature and hence the necessity. This has led to the formation of ethical committees in various institutions to review research proposals of intending researchers and advise them on the way to review the number of animals to be used for their research.

Cruelty to Animals

The term "animal cruelty" may mean something very different to a hunter or a farmer than it does to an animal activist. Animal cruelty has a legal definition as well. Since the very inception of the animal protection movement, there has been a conundrum caused by the various definitions of what constitutes animal cruelty. Even while there has been significant improvement for animals in our culture, especially over the past 50 years, there is still no universally recognized definition of what constitutes animal cruelty, which is a major roadblock. Every practice that endangers animals' welfare and has not already been stopped by law needs to be opposed and overcome mostly on an individual basis.

Whether it's the guy who kills the neighbour's cat, the hoarder of sick and dying animals, or the family whose cold, starved dog is tied up outside in the middle of winter, examples of animal cruelty make headlines around the world every day. These actions would probably be considered animal cruelty using the definition of the term as it is understood by the general population. People's understanding of the word "animal cruelty" varies significantly when it comes to animals other than cats and dogs. Most animal activists would agree that traditional farming methods including castration, debeaking, tail docking, and confinement on industrial farms are harsh to animals. Also, many people would undoubtedly concur, but industrial farmers and most states' laws against animal cruelty would be in opposition.

While some people may base their definition of cruelty on how much an animal suffers or hurts before it dies, animal rights activists do not care how much an animal suffers since they are denying them the right to exist and live without being used or abused by humans. Some people may also define something based on the kind of animal involved or how

intelligent they believe the animal to be. Some people may view the killing of cattle, pigs, and chickens as acceptable while viewing the slaughter of dogs, horses, or whales as the height of cruelty. Similar to how killing animals for sustenance is permissible, killing them for testing fur or cosmetics may be considered inappropriate animal cruelty.
The likelihood that the public will be offended and refer to the harm done to the animal as animal cruelty increases with the cultural familiarity of the animal and the unusualness of the harm. Cruelty, in the eyes of animal activists, encompasses a considerably larger spectrum of wrongs. Animal rights activists would contend that harming animals is harming animals, regardless of how widespread or acceptable the suffering is.
According to the California Penal Code, animal cruelty is defined as the willful or negligent maiming, mutilation, torture, or wounding of a living creature. It is also illegal to overwork, torture, torment, or deny an animal food, water, or shelter, as well as to beat, mutilate, or cruelly kill an animal. Any person who knowingly attends a dog fighting exhibition as a spectator or who owns, keeps, trains, or possesses a dog with the intent to use it in exhibition fighting is guilty of a misdemeanour. Additionally, it is a misdemeanour for anyone to willfully abandon any animal.

The following categories of animal cruelty are now recognized on a global scale:

1. Simple Neglect: This occurs when one or more animals are not given enough food, shelter, water, or veterinary care, typically out of ignorance. In the modern world, this type of animal cruelty is the most prevalent. Today, chaining dogs around the neck without a dog belt and leaving them to stand still in the backyard for hours or even days without sufficient shelter are the most prevalent examples of simple neglect. This type of cruelty or abuse often leads to the generation of wounds around the neck, choking up and at times death.

2. Gross Neglect: Willful, malevolent, or cruel neglect are other names for gross neglect. It is vital to distinguish between merely failing to provide proper care for animals and purposefully or knowingly denying them food or water to keep them from starving or dehydrating which constitutes gross neglect. People who cruelly discard ailing pets, some of whom are left outside in the rain or cold, are an example of this form of cruelty. Some abandon their animals in the clinic, or former apartment and some may sell them for money.

3. Intentional/purposeful Abuse: The public is more concerned about cases of purposeful cruelty, which are also more likely to include young perpetrators. There is a real concern that those who commit violent crimes against animals pose a threat to the public. One of the most obvious aspects of a history of aggressive or antisocial behaviour, intentional animal abuse is frequently encountered in conjunction with other significant crimes such as drug offences, gang activity, weapons violations, sexual assault, and domestic violence. Since the impact of the crime on the victim may be easier to prove and the purpose of the offence is more readily recognized, these cases are frequently easier to prosecute than neglect or hoarding cases. Some of the examples in Nigeria are cutting animals with cutlasses, pouring hot water/ashes on animals, pouring acids on animals, putting hot ashes in the mouth of animals and intentionally throwing animals from high pedestals.

4. Hoarding of animals: This results from the accumulation of numerous animals, the failure to meet the bare minimum requirements for nutrition, sanitation, and veterinary care, the failure to act on the animals' deteriorating conditions, and the failure to acknowledge or address the detrimental effects on the health and wellbeing of the household occupants. Animal hoarding incidents include, among others, the inhumane transportation of large numbers of animals, the housing of birds and other animals in substandard conditions, the starvation of pigs and other animals on farms, etc.

5. Organized Abuse/Cruelty: Animals fighting: Since the beginning of anticruelty statutes in the United States and the United Kingdom in the 19th century, "blood sports" like dog fighting and cockfighting have received special attention. This act is illegal according to the Federal Republic of Nigeria's constitution. In this act, two or more dogs, cocks, or other animals are placed in a battle circle and permitted to kill each other mercilessly for the sole amusement of the onlookers. Some of these animals are drugged before the fight.

6. Violent Ritual Abuse: The phrase "Occult and ritualistic animal abuse" immediately conjures up several disturbing images, including a cat burned at the stake, a dog's head left on a building's steps with a piece of paper containing a curse, strangulation of chicken, cutting of the head of a dog and a goat's throat cut as part of a ritual sacrifice. There are not many crimes that cause a community as much anxiety as crimes against animals. Fears of "satanic" or cult activities and worries about what additional crimes the perpetrators of such acts may have committed or be capable of arise almost quickly in many cases when animals are killed or maimed and left where they would be discovered.

7. Bestiality: Animal Sexual Assault: A human's affinity, interest, or sexual attraction to non-human animals is known as bestiality. Even though most people believe that using an animal for sex constitutes a sin against nature and is as disgusting and repulsive as it sounds, the problem of bestiality has been causing concern throughout the world including Nigeria. There is so much news about this both locally and internationally. However, some countries have approved bestiality.

Summary

Animals have been identified as an integral part of the world and hugely relied upon for food, as research models, companions, working animals, sports and in recreation. The increased public concern for action to improve animal welfare has necessitated the demand for animal welfare science study which seeks to improve basic understanding of the nature of animal emotions and motivations, and from this, improve the quality

of care given to these animals. Animal welfare entails all the conditions that may affect the physical and emotional state of the animal vis-a-vis its ability to cope especially with regards to its quality of life. The animal welfare act establishes a legal and regulatory framework for animal population dynamics in relation to animal welfare, human transportation, killing, disposal, and care of animals during the crisis as well as animal freedom and behaviour. According to the Animal Welfare Act and Animal Welfare Regulation, animal suffering should be prevented in all circumstances. These bodies suggested "Humane destruction of animals" or Humane euthanasia, which is usually carried out only if this is in the best interest of the animal's welfare. This means preventing further suffering, whether physical or mental, especially if the animal cannot be rehabilitated with the view to either release, in case of wildlife species, or rehome as in domesticated animals. Humane euthanasia must be carried out by a Veterinarian or Veterinary Technician and must be accompanied by methods that produce rapid unconsciousness and subsequent death without evidence of pain or distress. The use of animals for biomedical research remains essential to the discovery of the causes, diagnosis, and treatment of diseases and suffering in humans and animals. However, the use of these animals requires stipulated guidelines that include ethical approval for research that involves the use of animals under the Animal Research Advisory Committee (ARAC). The committee is made up of at least 5 people that include at least one veterinarian, with a direct or delegated program responsibility. Others are practicing scientists experienced in research involving the use of animals, a member whose primary concern is in a non-scientific area and lastly, a non-affiliated member representing the community interest in the proper care and use of animals. This committee assesses several animals to be used, feeding regime, housing, and types of medication (must not be radioactive materials, biohazardous, or hazardous materials). The authors of the research must submit a proposal before commencement. ARAC approves the commencement of research and can also withdraw approval if authors fail to adhere to the standard rules. Members of the committee can pay unscheduled visits to animal research sites to

ascertain animal rights and ensure the research does not impinge upon animal welfare standard practices.

Exercises

1. When will you consider an animal to be in a poor state of welfare?
2. What is "Humane euthanasia" in animal welfare?
3. What is the acceptable ethical framework that should be considered in the use of animals for scientific experimental research?
4. What is the full meaning of the acronym 'ARAC'?

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