La-Net

AGE 204

ANATOMY AND PHYSIOLOGY OF FARM ANIMALS

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Course code: AGE 204

Course title: Anatomy and Physiology of Farm Animals

Course credit load: 2 Units

Series 1: Topographical and Descriptive Terms in Animal Anatomy

- **Part 1.1: Introduction to Animal Anatomy**
  - Sub Part 1.1.1: Definition and scope of anatomy and physiology
  - Sub Part 1.1.2: Importance of anatomy and physiology to animal production
  - Sub Part 1.1.3: Major body systems and their interrelationships
- **Part 1.2: Anatomical Planes, Directions, and Regions**
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Introduction

Before a student can understand how a cow digests feed, how a chicken's heart pumps blood, or how a goat's kidney filters waste, they must first learn the language of anatomy. The directional and descriptive terms used in veterinary and animal science create a shared vocabulary that makes description of the animal body precise regardless of the position of the animal or the observer.

The aim of this Series is to introduce the scope of anatomy and physiology in farm animal production, to establish the standard terms for body planes, directions, regions, and cavities, and to review the organisation of the animal body from cell to tissue to organ to system. We shall begin with anatomy and physiology definitions, move through planes and directional terms, examine the body cavities, and conclude with cellular and tissue organisation.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 1.1** define anatomy and physiology and distinguish between gross and microscopic anatomy (Linked to Part 1.1),
- **SLO 1.2** explain the importance of anatomy and physiology to farm animal production (Linked to Part 1.1),
- **SLO 1.3** name the major body systems of farm animals and describe their general functions (Linked to Part 1.1),
- **SLO 1.4** define and correctly use the standard anatomical planes and sectional terms (Linked to Part 1.2),
- **SLO 1.5** apply directional terms correctly to describe the location of structures on farm animal bodies (Linked to Part 1.2),
- **SLO 1.6** identify the major topographical regions of cattle, sheep, goats, pigs, and poultry (Linked to Part 1.2),
- **SLO 1.7** identify and describe the contents of the thoracic, abdominal, and pelvic cavities (Linked to Part 1.3),

- **SLO 1.8** describe the serous membranes lining body cavities and explain their function (Linked to Part 1.3), and
- **SLO 1.9** describe the animal cell, the four tissue types, and the hierarchical organisation from cell to organ system (Linked to Part 1.4).

1.1 Introduction to Animal Anatomy

1.1.1 Definition and scope of anatomy and physiology

Anatomy is the science of the structure of living organisms. Gross anatomy studies structures visible to the naked eye such as organs, bones, and blood vessels. Histology examines tissues under the microscope, and cytology examines individual cells. Comparative anatomy compares structures across species, which is essential for understanding how cattle, sheep, pigs, and poultry differ in body organisation.

Physiology is the science of how organisms function. It explains mechanisms such as rumen fermentation, kidney filtration, and hormonal control of reproduction. Anatomy and physiology are inseparable: structure determines function, and understanding function requires knowledge of the underlying structure. Together they form the scientific foundation of all farm animal management disciplines.

Fill in the blank: _____ is the science of structure while physiology is the science of function; both are studied together as the foundation of farm animal production.

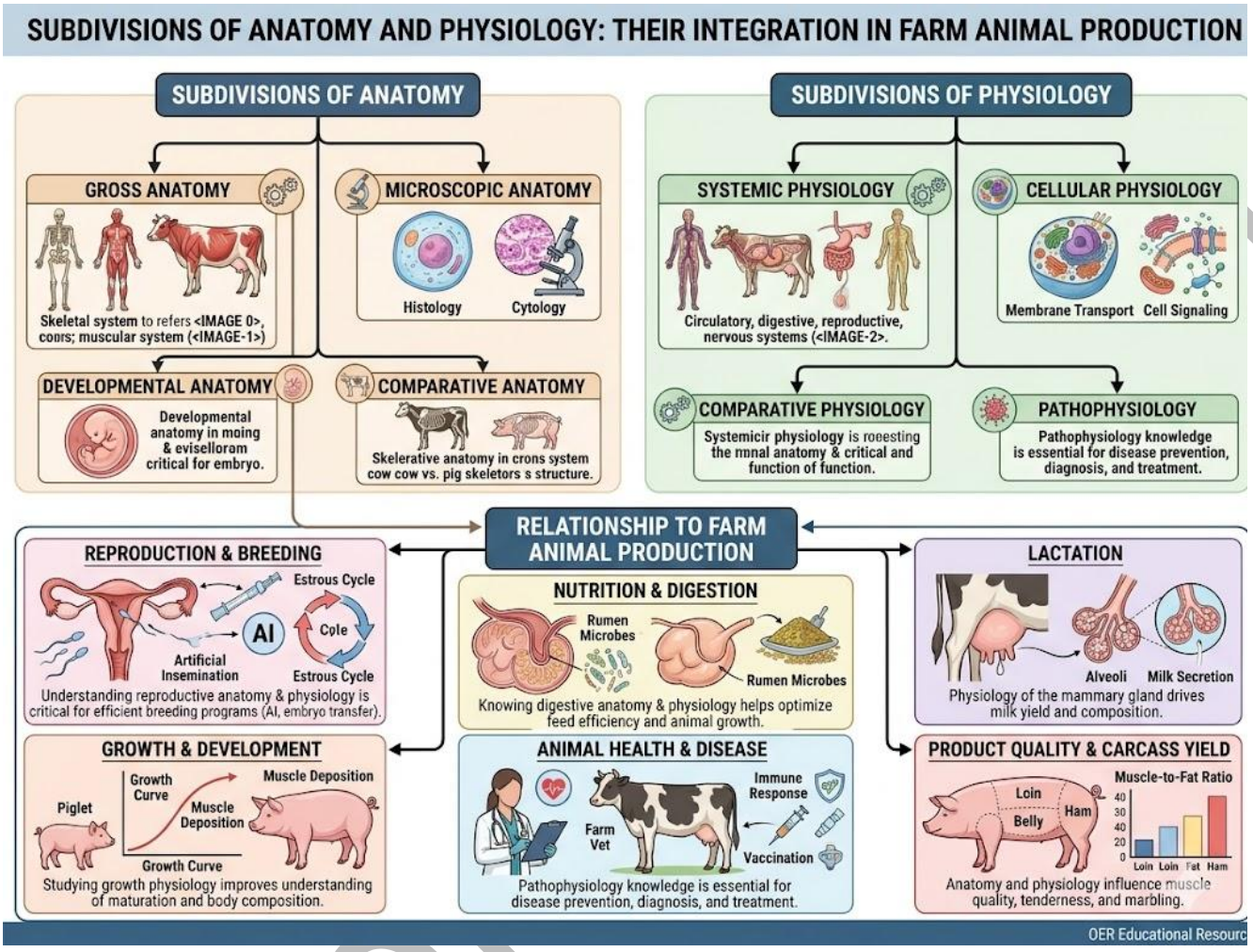

Figure 1.1: Diagram showing the subdivisions of anatomy and their relationship to physiology in farm animal science

1.1.2 Importance of anatomy and physiology to animal production

Knowledge of anatomy and physiology underpins every practical decision in farm animal production. Feeding programmes are designed around the digestive anatomy of each species: ruminants have a multi-chambered fermentation stomach, so rations must support rumen function, while poultry lack a rumen entirely and require directly digestible feeds. Reproductive management depends on knowledge of the reproductive tract, oestrous cycle, and mechanisms of parturition.

Health management requires anatomical knowledge to locate lesions, interpret clinical signs, and perform procedures such as injections and catheterisation at the correct site. Production assessment depends on understanding how the mammary gland produces milk, how muscle is deposited in the carcass, and how the integument reflects nutritional status. Anatomy and physiology are the conceptual framework within which nutrition, breeding, and health courses are integrated.

Fill in the blank: Feeding programmes for ruminants are designed around the _____ anatomy, specifically the fermentation function of the multi-chambered stomach that distinguishes them from poultry.

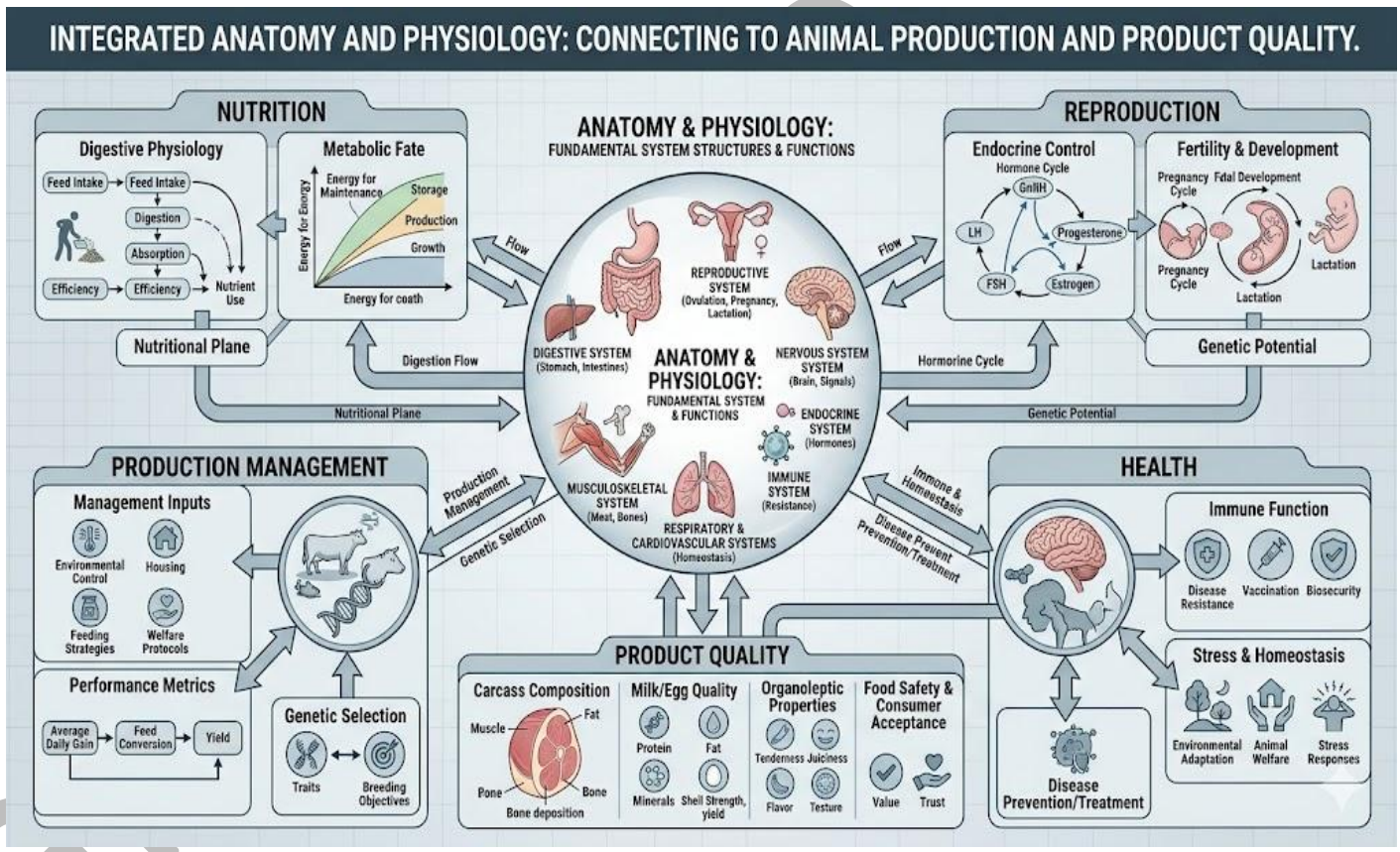

Figure 1.2: Diagram showing anatomy and physiology at the centre connected to the practical disciplines of animal production

1.1.3 Major body systems and their interrelationships

The body of a farm animal is organised into systems that work together to maintain life and support production. The major systems are: skeletal (support and movement), muscular (locomotion), integumentary (body surface protection), digestive (nutrient processing), cardiovascular (blood circulation), lymphatic (immune defence and fluid balance), respiratory (gas exchange), urinary (waste elimination), nervous (coordination), endocrine (hormonal regulation), and reproductive (offspring production).

No system operates in isolation. The digestive system delivers nutrients that the cardiovascular system transports to every cell; the nervous and endocrine systems coordinate all others. This interconnection means that a problem in one system has consequences throughout the animal. Anaemia from parasitism, for example, reduces oxygen delivery and impairs growth, immune function, and reproductive performance simultaneously.

Fill in the blank: The animal body is organised into organ _____, each performing specific functions, but no system operates independently as all are interconnected through the cardiovascular, nervous, and endocrine systems.

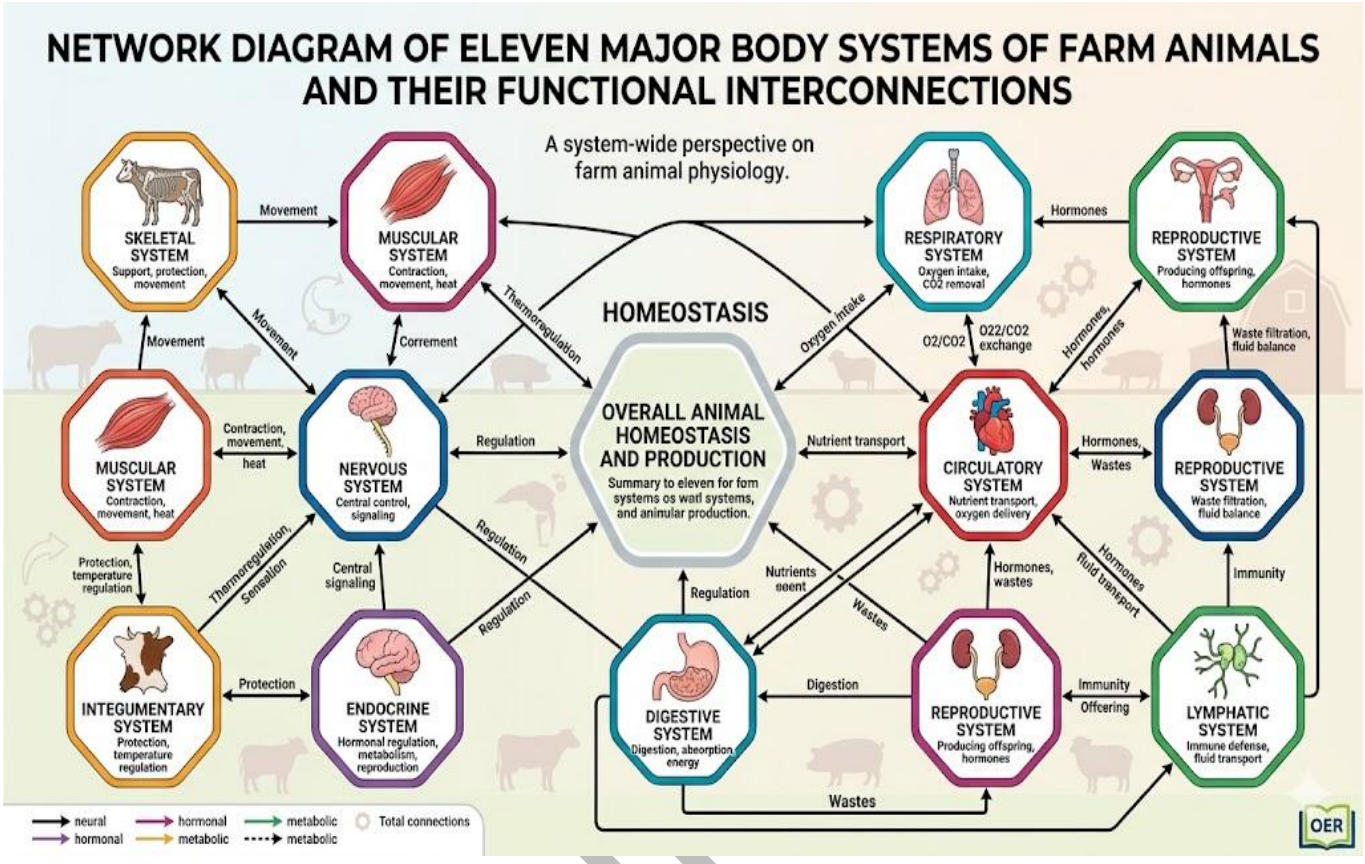

Figure 1.3: Network diagram showing the eleven major body systems of farm animals and their primary interconnections

Pilot questions 1.1

1. Define anatomy and physiology and explain why they are studied together.
2. Distinguish between gross anatomy, histology, and cytology.
3. Explain how knowledge of the digestive system influences feeding programmes for ruminants versus poultry.
4. Name seven major body systems of farm animals and state the primary function of each.
5. Explain why anaemia caused by parasitism can affect multiple body systems simultaneously.

1.2 Anatomical Planes, Directions, and Regions

1.2.1 Body planes and sections

Anatomical planes are imaginary flat surfaces used to describe the orientation of structures within the body. The median plane (midsagittal plane) passes through the midline from head to tail, dividing the body into equal left and right halves. Paramedian (sagittal) planes run parallel to the median but off-centre. The transverse plane passes at right angles to the long axis, dividing the body into cranial and caudal portions.

The dorsal plane (horizontal or frontal plane) runs parallel to the dorsal surface and divides the body into dorsal and ventral portions. A cut through any of these planes produces a named section: a median section, a transverse section (cross-section), or a dorsal section. These terms appear consistently in veterinary anatomy texts and clinical descriptions to allow readers to accurately visualise the orientation of any described structure.

Fill in the blank: The _____ plane passes through the midline from head to tail, dividing the body into equal left and right halves, and a cut through it produces a median section.

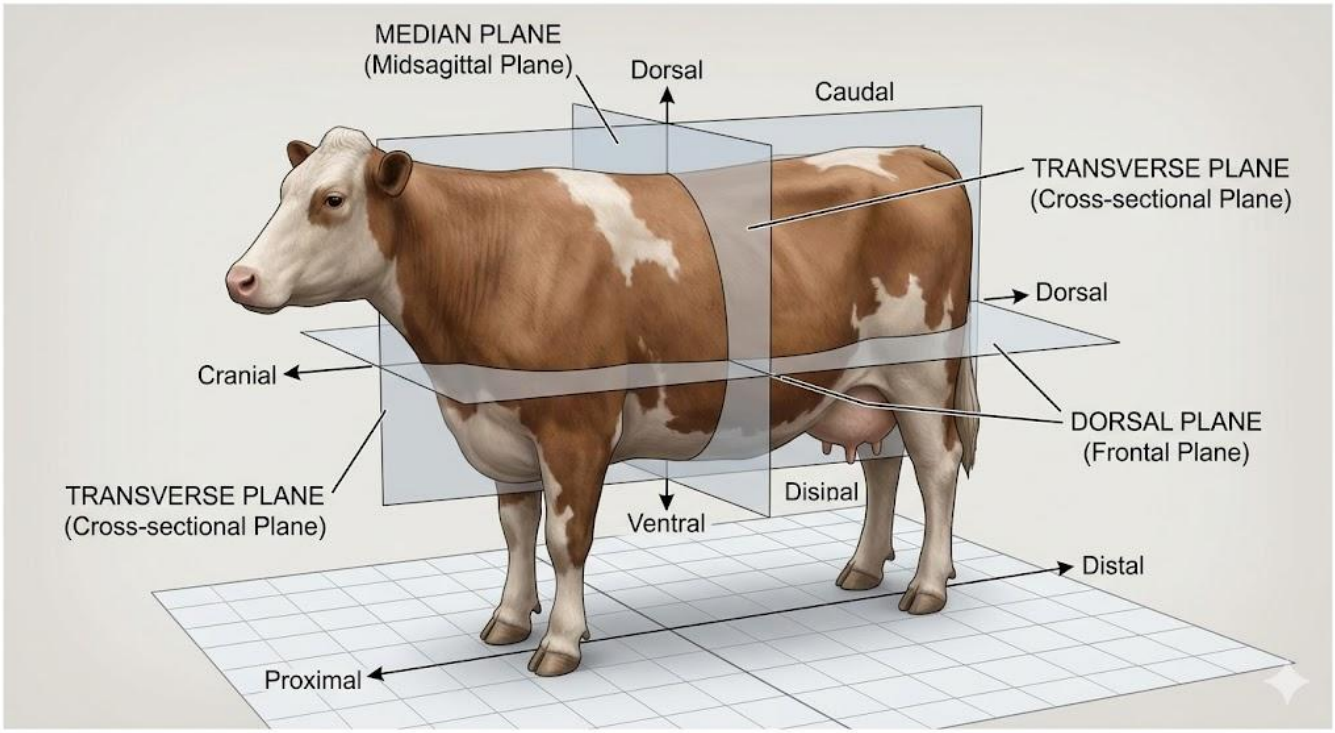

Figure 1.4: Three-dimensional diagram of a cow showing the median, transverse, and dorsal anatomical planes

1.2.2 Directional and positional terms

Directional terms describe the relative position of one structure with respect to another. Cranial means towards the head; caudal means towards the tail. Dorsal means towards the back or upper surface; ventral means towards the belly. Medial means towards the median plane; lateral means away from it. Proximal means nearer to the point of limb attachment to the trunk; distal means farther away.

Additional terms include: palmar (the caudal surface of the forefoot below the carpus), plantar (the caudal surface of the hindfoot below the tarsus), superficial (closer to the body surface), and deep (further from it). In birds, dorsal, ventral, cranial, and caudal are used; the terms anterior and posterior common in human anatomy are avoided in veterinary anatomy because the quadruped body plan makes them ambiguous.

Fill in the blank: In directional anatomy, _____ means towards the head while caudal means towards the tail; these terms describe relative position along the length of the trunk and proximal limb.

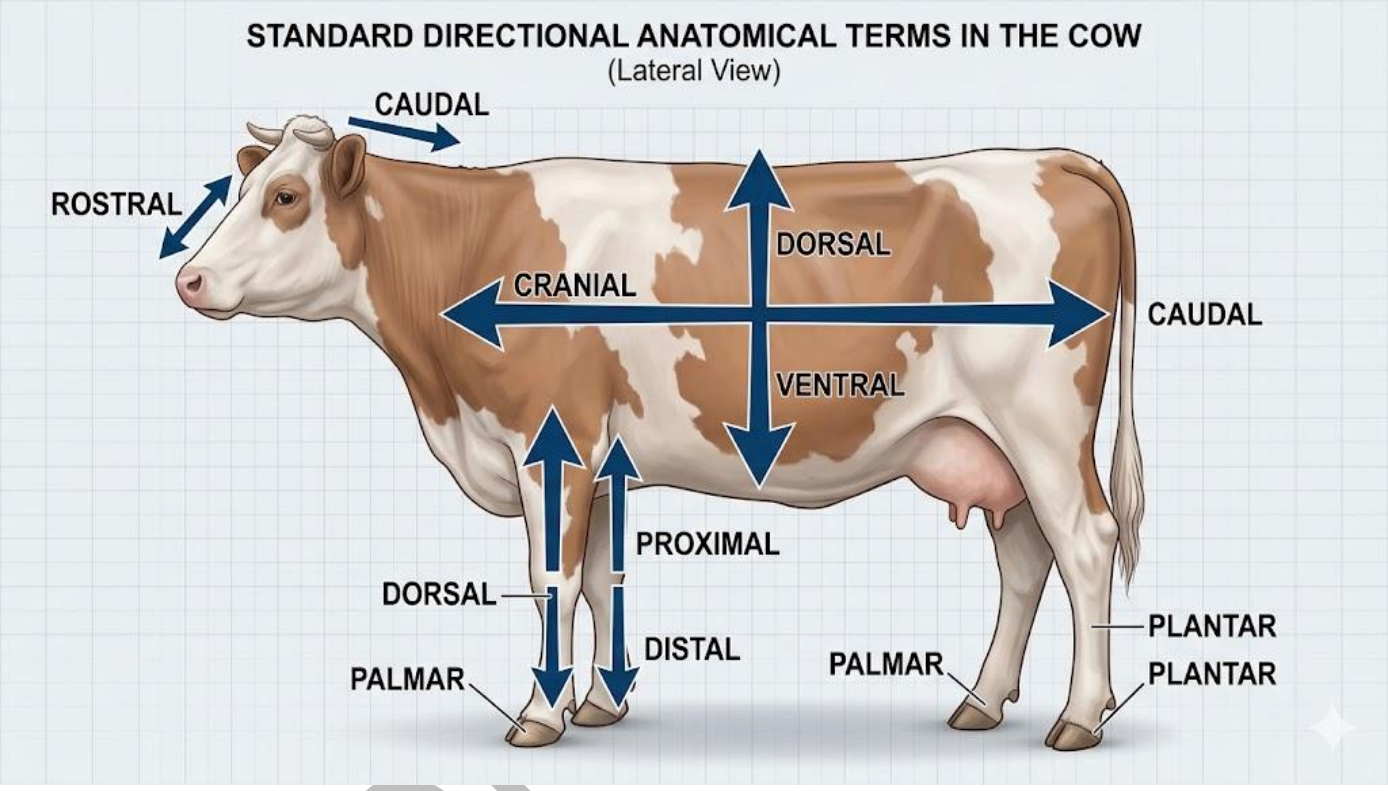

Figure 1.5: Labelled diagram of a cow in lateral view showing standard directional terms

1.2.3 Topographical regions of the body

Topographical regions are named areas of the body surface used to communicate precisely about the location of observations, lesions, and injection sites. In cattle, the major trunk regions include: the neck (cervical region), withers (over the thoracic vertebrae above the shoulder), back (thoracic and lumbar), loin (lumbar), croup (sacral and gluteal), flank (lateral abdominal wall between the last rib and hip), abdomen (ventral wall), and udder region.

In sheep and goats the regional terminology follows the same plan as cattle but with different proportions. In pigs the terminology is similar with modifications for the upright neck and short legs. In poultry, the regions include the head (with comb, wattles, and beak), neck, breast, back, wing, thigh, leg (shank), vent region, and tail. Knowing topographical regions allows precise

documentation of clinical findings and improves communication between producers and veterinarians.

Fill in the blank: The _____ region of cattle is the lateral abdominal wall between the last rib and the hip and is the site of rumen auscultation and left flank laparotomy.

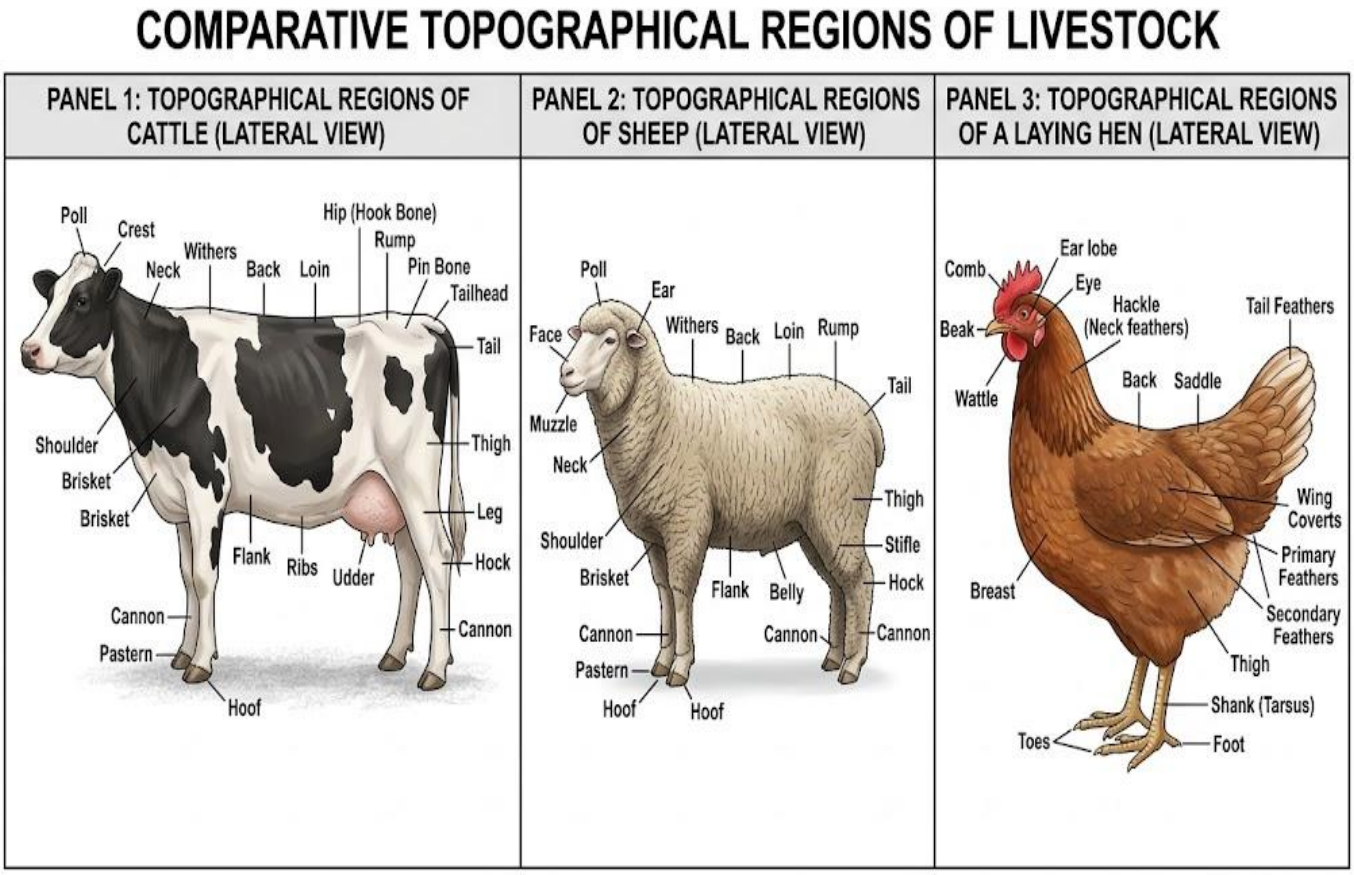

Figure 1.6: Three-panel diagram showing labelled topographical regions of cattle, sheep, and a laying hen

Pilot questions 1.2

1. Name and describe the three standard anatomical planes used in veterinary anatomy.
2. Explain the difference between a median section and a transverse section.
3. Define the directional terms cranial, caudal, dorsal, ventral, medial, and lateral.
4. Explain the difference between proximal and distal when applied to limb structures.
5. Name four major topographical regions of cattle and state a practical significance of each.

1.3 Body Cavities and Their Contents

1.3.1 The thoracic cavity and its organs

The thoracic cavity is enclosed by the rib cage and bounded caudally by the diaphragm. It contains the most critical organs of the cardiovascular and respiratory systems. The lungs occupy the right and left pleural cavities. The heart lies within the pericardium in the mediastinum, the central partition between the two pleural cavities. The great vessels (aorta, pulmonary artery and veins, venae cavae) enter and leave the heart within the mediastinum.

The mediastinum also contains the trachea, oesophagus, thoracic duct, phrenic nerve (innervating the diaphragm), and vagus nerve (passing through to the abdominal organs). The diaphragm is a dome-shaped sheet of skeletal muscle; when it contracts it flattens, increasing thoracic volume and drawing air into the lungs. In poultry, the thoracic and abdominal cavities are not separated by a complete muscular diaphragm as in mammals.

Fill in the blank: The _____ is the dome-shaped skeletal muscle separating the thoracic from the abdominal cavity; its contraction flattens it, increasing thoracic volume and drawing air into the lungs.

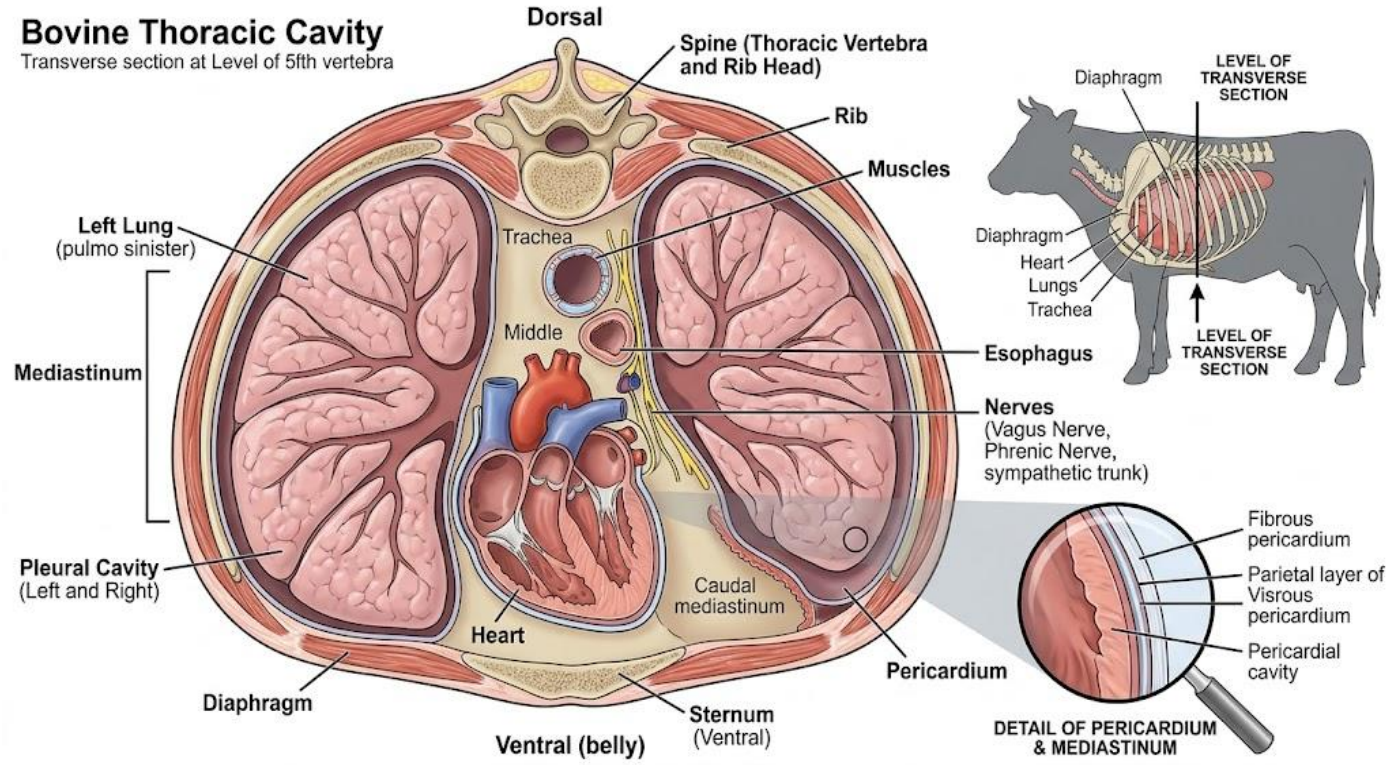

Figure 1.7: Cross-section diagram of the bovine thoracic cavity showing major organs and their positions

1.3.2 The abdominal and pelvic cavities

The abdominal cavity is caudal to the diaphragm and cranial to the pelvic inlet. It contains the majority of the digestive organs. In cattle and other ruminants it is dominated by the rumen and reticulum on the left and the omasum and abomasum on the right, along with the small intestine, large intestine, liver (right side), spleen (left side), pancreas, and kidneys. In pigs and other monogastrics a single-chambered stomach is present and the intestinal mass fills more of the cavity.

The pelvic cavity is enclosed by the pelvic bones and contains the terminal portion of the large intestine (rectum), the urinary bladder, and the reproductive organs. In females, the ovaries, uterine tubes, uterus, and cranial vagina lie in the pelvic area. The pelvic inlet and outlet are critical anatomical boundaries in reproductive management, particularly in assessing whether the maternal pelvis is large enough for unobstructed parturition.

Fill in the blank: The pelvic _____ is the caudal opening of the pelvic cavity through which the birth canal passes, and its dimensions are assessed when determining ease of parturition.

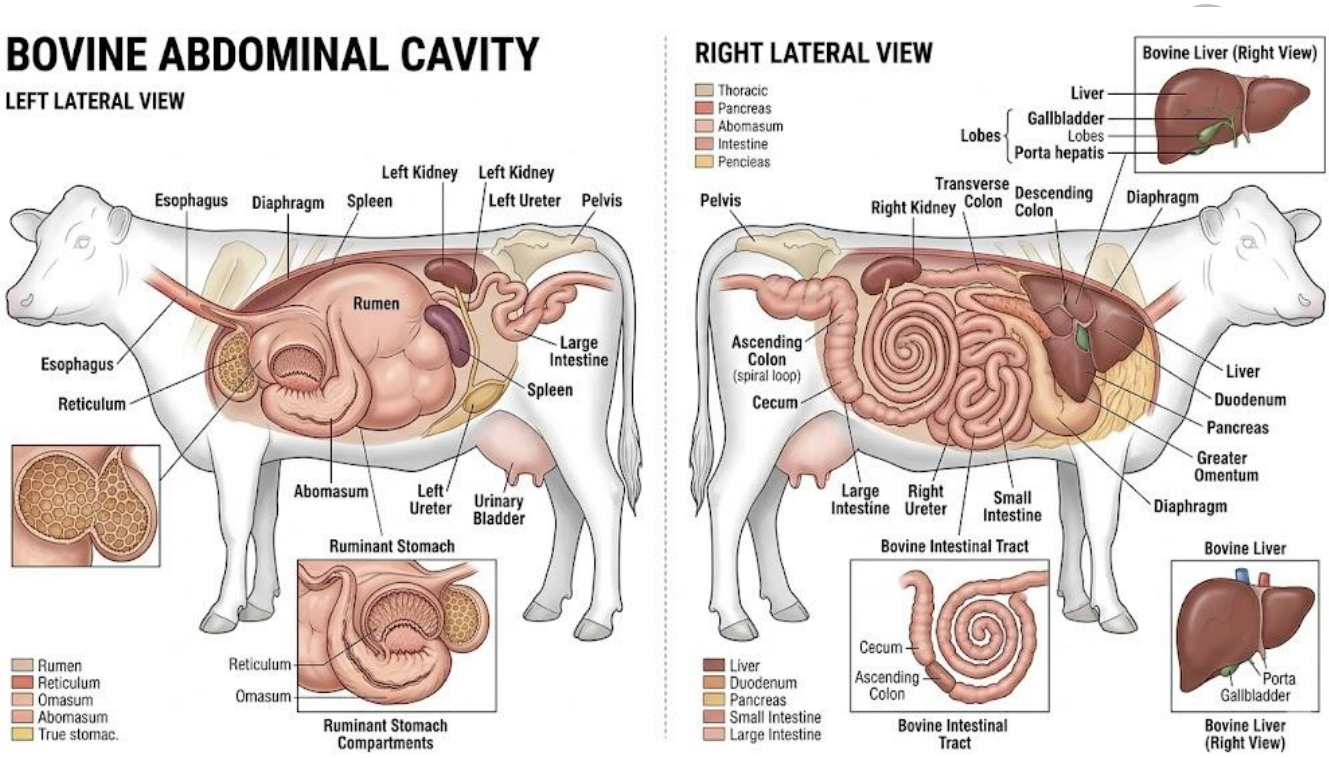

Figure 1.8: Diagram of the bovine abdominal cavity showing major organs in left and right lateral views

1.3.3 Serous membranes lining body cavities

Serous membranes are thin, smooth sheets that line body cavities and cover the organs within them, secreting a small amount of serous fluid that lubricates surfaces and allows organs to move against each other without friction. Each serous membrane consists of two layers: the parietal layer lines the inner wall of the body cavity, and the visceral layer covers the outer surface of the organs. The potential space between them is the named cavity proper.

The three serous membranes are: the pleura (lining the thoracic cavity and covering the lungs, with pleural fluid between the layers), the pericardium (a double-layered sac enclosing the heart, with pericardial fluid between the layers), and the peritoneum (the largest, lining the abdominal and pelvic cavities, with peritoneal fluid between the layers). Inflammation of these membranes,

called pleuritis, pericarditis, or peritonitis, causes pain and may produce excessive fluid or fibrous adhesions.

Fill in the blank: The _____ is the largest serous membrane, lining the abdominal and pelvic cavities and covering the abdominal organs; its inflammation is called peritonitis.

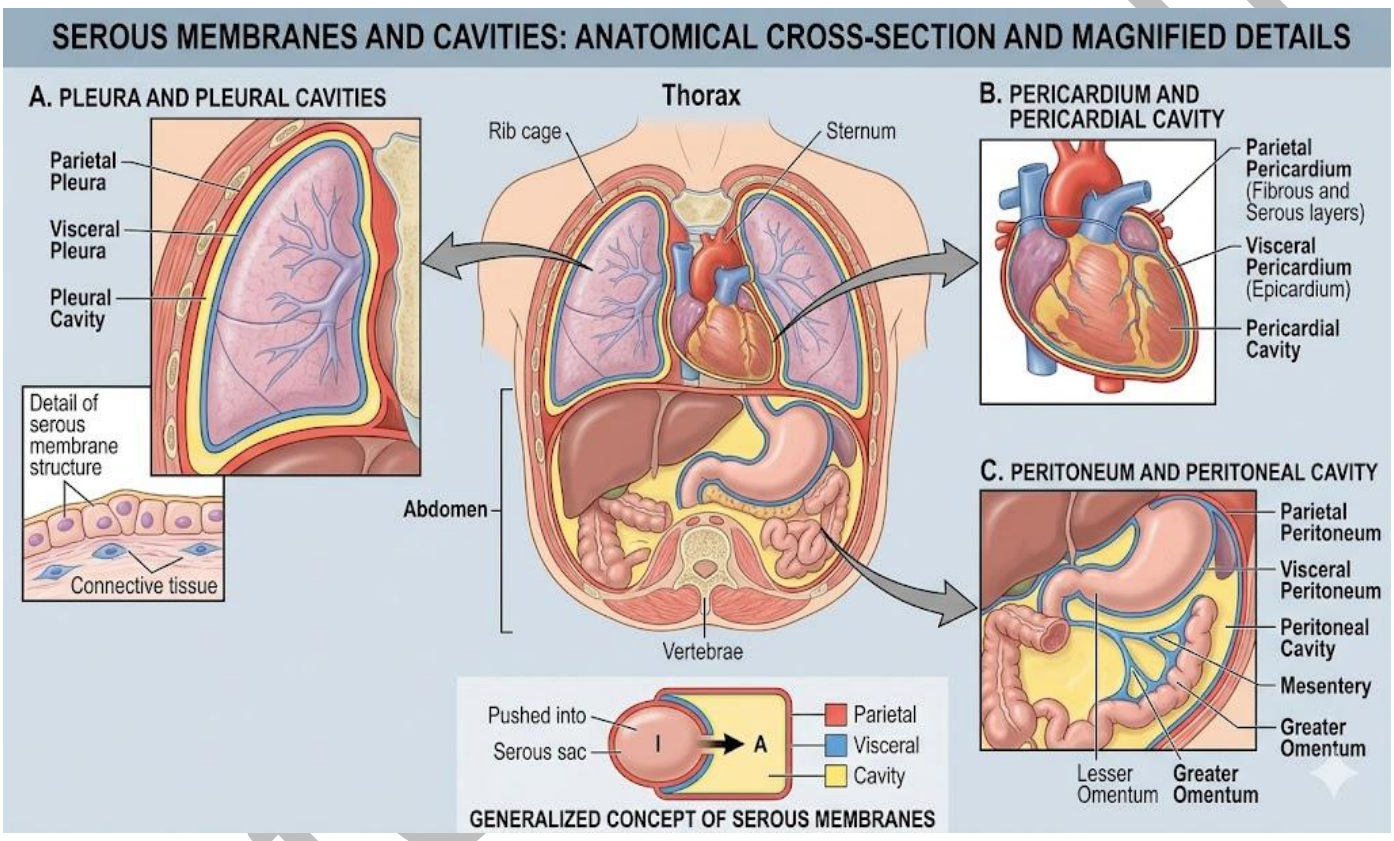

Figure 1.9: Diagram showing the parietal and visceral layers of the pleura, pericardium, and peritoneum

Pilot questions 1.3

1. Name the organs contained in the thoracic cavity of a mammal.
2. Explain the function of the diaphragm in breathing.
3. Describe the contents of the abdominal cavity of a ruminant and how they differ from a monogastric animal.
4. Explain the function of serous membranes and describe their two layers.
5. Name the three serous membranes, the cavity each lines, and the clinical condition caused by inflammation of each.

1.4 Cells, Tissues, and Organs

1.4.1 The animal cell

The cell is the basic structural and functional unit of all living organisms. An animal cell is bounded by the cell membrane, a selectively permeable phospholipid bilayer that regulates entry and exit of substances. The cytoplasm is the fluid-filled interior in which the organelles are suspended. The nucleus contains the cell's DNA and controls cell activity and reproduction.

The major organelles include the mitochondria (generating ATP by aerobic respiration, the powerhouses of the cell), rough and smooth endoplasmic reticulum (protein and lipid synthesis), ribosomes (protein synthesis sites), Golgi apparatus (packaging and secreting proteins and lipids), and lysosomes (containing digestive enzymes for intracellular breakdown of waste). Different cell types are specialised in structure to match their function: muscle cells are packed with contractile proteins; nerve cells have long extensions for impulse conduction.

Fill in the blank: The _____ generates ATP by aerobic respiration and is described as the powerhouse of the cell; cells with high energy demands contain large numbers of them.

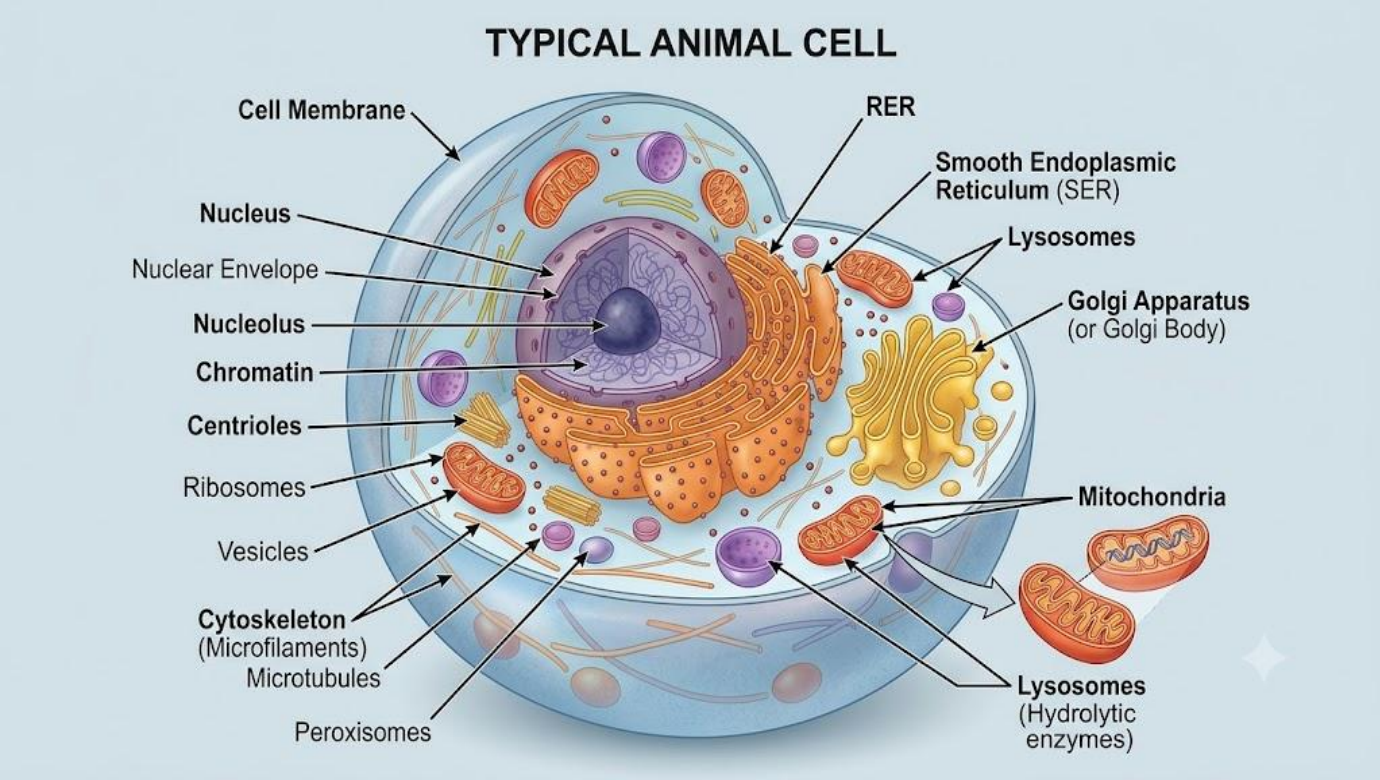

Figure 1.10: Labelled diagram of a typical animal cell showing major organelles

1.4.2 The four tissue types

A tissue is a group of similar cells performing a common function. Epithelial tissue covers body surfaces, lines hollow organs, and forms glands; it is characterised by tightly packed cells and high regenerative capacity, and functions in protection, secretion, and absorption. Connective tissue supports and connects other tissues; its cells are embedded in an abundant extracellular matrix and it includes bone, cartilage, blood, and adipose tissue.

Muscle tissue is specialised for contraction: skeletal muscle is under voluntary control and moves the skeleton; cardiac muscle is involuntary and self-stimulating, pumping blood; smooth muscle is involuntary and controls hollow organ diameter and movement. Nervous tissue receives stimuli and transmits electrical impulses throughout the body; it is composed of neurons and supporting neuroglial cells. These four tissue types are the building blocks of every organ in the body.

Fill in the blank: The four fundamental tissue types are epithelial, connective, _____, and nervous tissue; each is specialised in structure to perform its role.

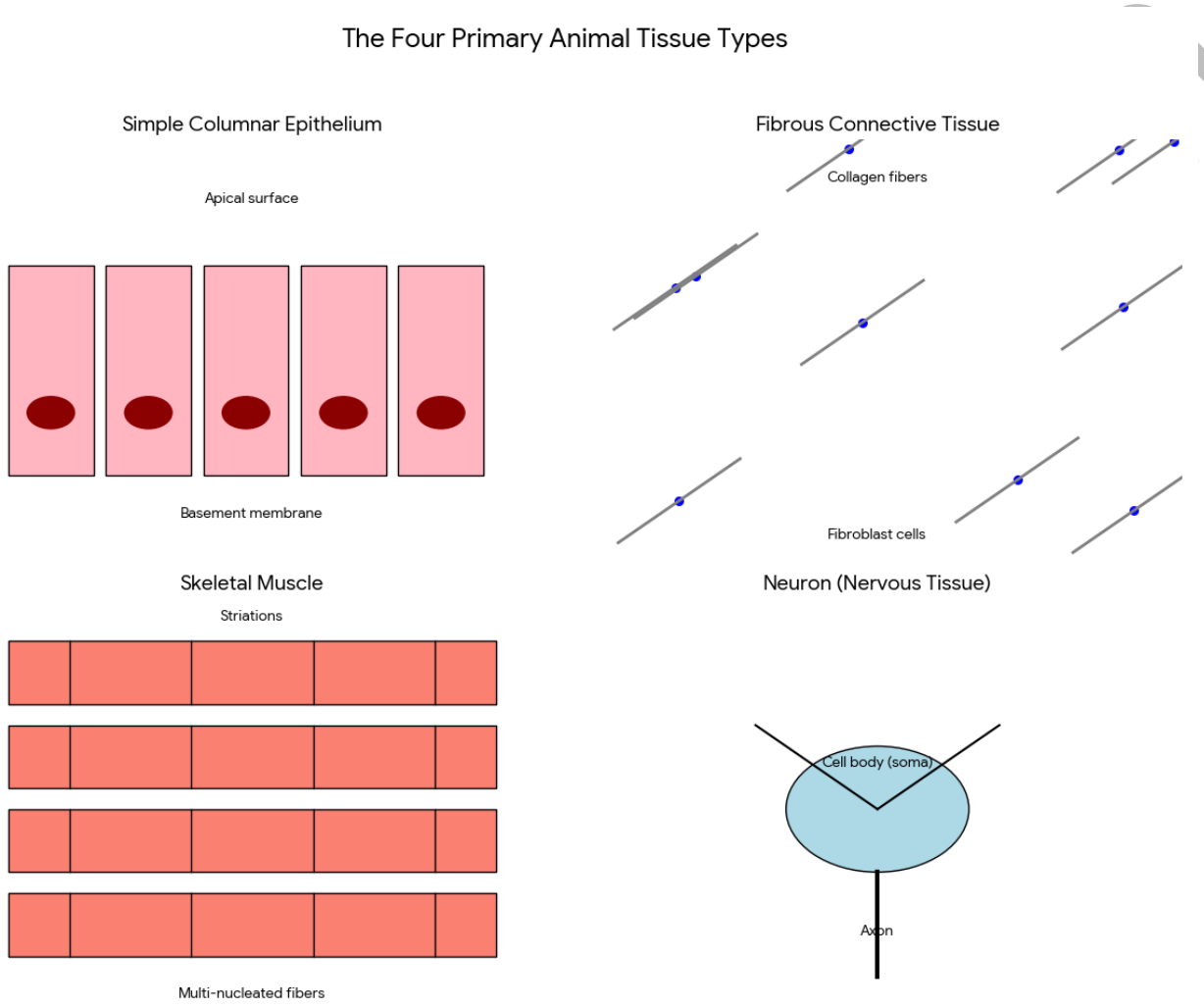

Figure 1.11: Four-panel diagram showing microscopic representations of the four tissue types

1.4.3 Organisation from tissue to organ to system

An organ is a structure composed of two or more tissue types organised to perform a specific function. The small intestine, for example, contains simple columnar epithelium (for absorption and secretion), smooth muscle layers (for peristalsis), connective tissue (for structural support and blood supply), and nervous tissue (the enteric nervous system controlling motility). An organ

system is a group of organs collectively performing a broader function, such as the digestive system.

The hierarchical organisation of the animal body proceeds from chemical molecules, through organelles, cells, tissues, organs, and organ systems, to the whole organism. A lesion at the cellular level has consequences at every level above it: viral destruction of liver cells causes hepatitis at the tissue level, liver failure at the organ level, metabolic collapse at the systems level, and death or production loss at the whole-animal level. This integrated view is the central lesson of applied animal anatomy.

Fill in the blank: An _____ is a structure composed of two or more tissue types organised to perform a specific function; the small intestine, for example, contains epithelial, smooth muscle, connective, and nervous tissue.

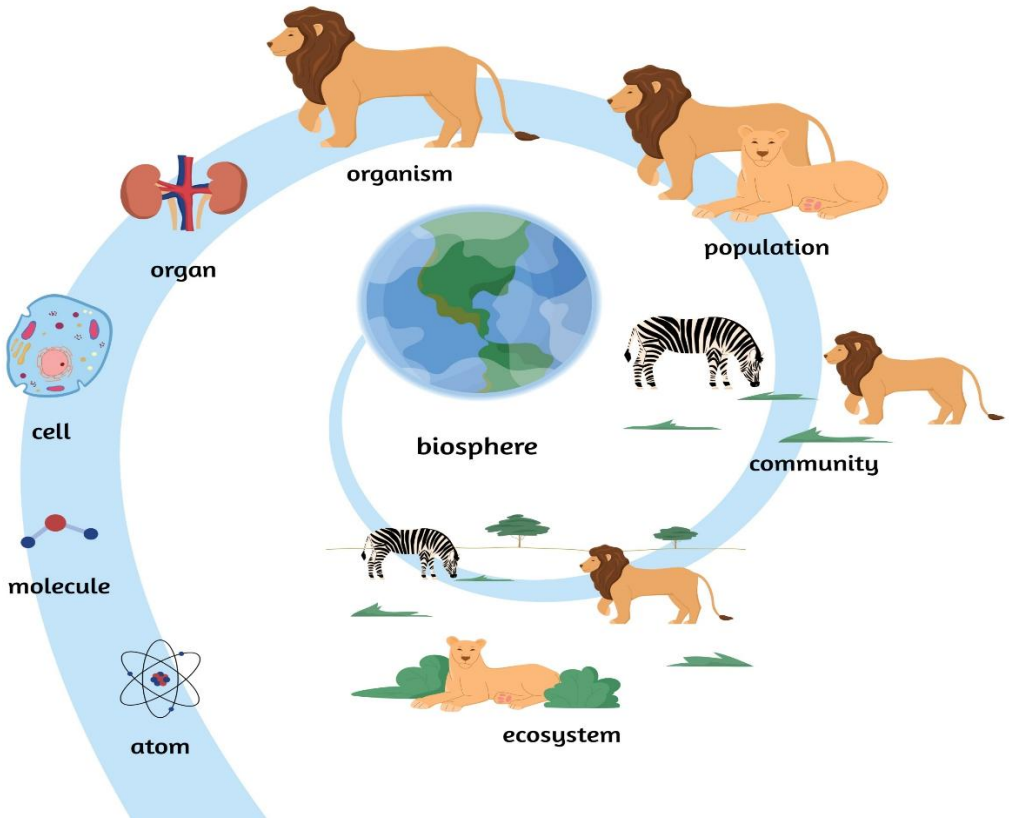

Figure 1.12: Vertical hierarchy diagram from chemical molecules to whole farm animal organism

Pilot questions 1.4

1. Name five organelles found in a typical animal cell and state the function of each.
2. Name the four tissue types and state the primary function and a structural characteristic of each.
3. Distinguish between simple and stratified epithelium and give one location for each in a farm animal.
4. Explain what an organ is and give one example showing which tissue types compose it.
5. Explain why viral destruction of liver cells can affect the performance of the whole animal.

Series Summary

This Series has established the vocabulary and conceptual framework for the study of farm animal anatomy and physiology. We defined anatomy (the science of structure) and physiology (the science of function) and described the eleven major body systems, emphasising that they are interconnected and that problems in one system cascade through others. We introduced the standard anatomical planes (median, transverse, dorsal), directional terms (cranial, caudal, dorsal, ventral, medial, lateral, proximal, distal, palmar, plantar), and the topographical regions of cattle, sheep, and poultry.

We described the three major body cavities: the thoracic cavity (containing the lungs and heart), the abdominal cavity (containing the digestive organs and differing markedly between ruminants and monogastrics), and the pelvic cavity (containing the terminal digestive, urinary, and reproductive organs). We explained the serous membranes (pleura, pericardium, peritoneum) and their clinical significance. Finally, we reviewed the animal cell and its organelles, the four tissue types, and the hierarchical organisation from cell to tissue to organ to organ system. By completing this Series, you should be able to achieve all nine Series Learning Outcomes (SLO 1.1 to SLO 1.9).

Glossary of Terms

- **Anatomy:** the science of the structure of living organisms; subdivided into gross anatomy, histology, and cytology.
- **Caudal:** towards the tail; opposite of cranial.
- **Cell membrane:** the selectively permeable phospholipid bilayer enclosing the cell and regulating passage of substances.
- **Connective tissue:** tissue that supports and connects other tissues; characterised by cells in an abundant extracellular matrix; includes bone, cartilage, blood, and adipose.
- **Cranial:** towards the head; opposite of caudal.
- **Cytology:** the branch of anatomy studying the structure and function of individual cells.
- **Diaphragm:** the dome-shaped skeletal muscle separating the thoracic and abdominal cavities; the primary muscle of breathing.
- **Distal:** farther from the point of limb attachment to the trunk; opposite of proximal.
- **Dorsal:** towards the back or upper surface; opposite of ventral.
- **Dorsal plane:** the plane parallel to the dorsal surface dividing the body into dorsal and ventral portions; also called the horizontal or frontal plane.
- **Epithelial tissue:** tissue covering body surfaces, lining hollow organs, and forming glands; tightly packed cells with high regenerative capacity.
- **Flank:** the lateral abdominal wall between the last rib and the hip; site of rumen auscultation and left flank laparotomy in cattle.
- **Golgi apparatus:** organelle that packages, modifies, and distributes proteins and lipids for secretion or intracellular use.
- **Gross anatomy:** the study of structures visible to the naked eye; also called macroscopic anatomy.
- **Histology:** the branch of anatomy studying the microscopic structure of tissues.
- **Lateral:** away from the median plane towards the side of the body; opposite of medial.

- **Lysosome:** organelle containing digestive enzymes that break down waste material and foreign particles within the cell.
- **Medial:** towards the median plane; opposite of lateral.
- **Median plane:** the plane through the midline dividing the body into equal left and right halves; also called the midsagittal plane.
- **Mediastinum:** the central partition of the thoracic cavity between the two pleural cavities; contains the heart, great vessels, trachea, and oesophagus.
- **Mitochondrion:** organelle generating ATP by aerobic respiration; the powerhouse of the cell.
- **Muscle tissue:** tissue specialised for contraction; includes skeletal (voluntary), cardiac (involuntary self-stimulating), and smooth (involuntary) types.
- **Nervous tissue:** tissue specialised for receiving stimuli and transmitting electrical impulses; composed of neurons and neuroglial cells.
- **Nucleus:** organelle containing the cell's DNA; controls cell activity and reproduction.
- **Organ:** a structure composed of two or more tissue types organised to perform a specific function.
- **Organ system:** a group of organs collectively performing a broader physiological function.
- **Palmar:** the caudal surface of the forefoot below the carpus in quadrupeds.
- **Parietal layer:** the layer of a serous membrane lining the inner wall of the body cavity.
- **Pelvic cavity:** the cavity enclosed by the pelvic bones containing the rectum, urinary bladder, and reproductive organs.
- **Pericardium:** the double-layered serous membrane enclosing the heart; its inflammation is pericarditis.
- **Peritoneum:** the largest serous membrane, lining the abdominal and pelvic cavities; its inflammation is peritonitis.
- **Physiology:** the science of how living organisms function.
- **Plantar:** the caudal surface of the hindfoot below the tarsus in quadrupeds.

- **Pleura:** the serous membrane lining the thoracic cavity and covering the lungs; its inflammation is pleuritis.
- **Proximal:** nearer to the point of limb attachment to the trunk; opposite of distal.
- **Serous membrane:** a thin smooth membrane lining body cavities and covering organs, secreting lubricating serous fluid.
- **Thoracic cavity:** the cranial body cavity enclosed by the rib cage and diaphragm, containing the lungs and heart.
- **Transverse plane:** the plane passing at right angles to the long body axis, dividing the body into cranial and caudal portions.
- **Ventral:** towards the belly or lower surface; opposite of dorsal.
- **Visceral layer:** the layer of a serous membrane covering the outer surface of organs within a body cavity.

Concept Check Questions [Series 1]

Objective Questions

1. _____ is the science of structure while physiology is the science of function; both underpin farm animal management. (Linked to SLO 1.1)
2. The _____ plane passes through the midline dividing the body into equal left and right halves. (Linked to SLO 1.4)
3. In directional anatomy, _____ means towards the head while caudal means towards the tail. (Linked to SLO 1.5)
4. The _____ is the dome-shaped skeletal muscle separating the thoracic and abdominal cavities. (Linked to SLO 1.7)
5. The mitochondrion generates _____ by aerobic respiration and is called the powerhouse of the cell. (Linked to SLO 1.9)

Short-Answer Questions

6. Distinguish between gross anatomy, histology, and cytology. (Linked to SLO 1.1)
7. Define six standard directional terms used in veterinary anatomy and give one example of each. (Linked to SLO 1.5)
8. Describe the contents of the thoracic cavity of a mammal. (Linked to SLO 1.7)
9. Explain the function of serous membranes and name the three serous membranes with the cavity each lines. (Linked to SLO 1.8)
10. Name the four tissue types, state the primary function of each, and give one organ example for each. (Linked to SLO 1.9)

Long-Answer Questions

11. Analyse the importance of anatomical and physiological knowledge to farm animal production, describing the major body systems, explaining their interconnections, and giving specific examples of how this knowledge influences practical management decisions in nutrition, reproduction, and health. (Linked to SLOs 1.2, 1.3)
12. Discuss the standard anatomical terminology used in veterinary anatomy, explaining the three planes and directional terms, and applying them to describe the positions of the major organs within the thoracic, abdominal, and pelvic cavities of a ruminant. (Linked to SLOs 1.4, 1.5, 1.6, 1.7)
13. Evaluate the hierarchical organisation of the animal body from cell to organ system, describing the animal cell and its organelles, the four tissue types, and explaining how a disease at the cellular level produces consequences throughout the whole animal. (Linked to SLOs 1.8, 1.9)

Answers to Concept Check Questions [Series 1]

Objective Questions

1. Anatomy.
2. Median.
3. Cranial.

4. Diaphragm.
5. ATP.

Short-Answer Questions

6. Gross anatomy studies structures visible to the naked eye such as organs, bones, muscles, and blood vessels. Histology studies the microscopic structure of tissues under the light or electron microscope. Cytology studies the structure and function of individual cells and their organelles.
7. Cranial: towards the head (the thorax is cranial to the abdomen). Caudal: towards the tail (the pelvis is caudal to the abdomen). Dorsal: towards the back or upper surface (the vertebral column is dorsal to the heart). Ventral: towards the belly (the sternum is ventral to the heart). Medial: towards the median plane (the trachea is medial to the lungs). Lateral: away from the median plane (the lungs are lateral to the heart).
8. The thoracic cavity contains the right and left lungs (each within its pleural cavity), the heart (within the pericardium in the mediastinum), the trachea, oesophagus, thoracic duct, great vessels (aorta, pulmonary artery, pulmonary veins, venae cavae), phrenic and vagus nerves, and the diaphragm at the caudal boundary.
9. Serous membranes are thin smooth sheets lining body cavities and covering organs; they secrete serous fluid that lubricates surfaces and allows frictionless organ movement; each has a parietal layer (lining the cavity wall) and a visceral layer (covering the organ). Three membranes: pleura (thoracic cavity and lungs, pleural cavity); pericardium (enclosing the heart, pericardial cavity); peritoneum (abdominal and pelvic cavities, peritoneal cavity).
10. Epithelial tissue: protection, secretion, absorption; found in the intestinal lining. Connective tissue: support, connection, transport, storage; found in bone and blood. Muscle tissue: contraction and movement; found in the heart wall. Nervous tissue: receives stimuli and conducts electrical impulses; found in the brain and spinal cord.

Long-Answer Questions

11. Basic response: Anatomy (structure) and physiology (function) underpin all management decisions. Eleven systems: skeletal, muscular, integumentary, digestive, cardiovascular,

lymphatic, respiratory, urinary, nervous, endocrine, reproductive. Systems are interconnected: cardiovascular transports nutrients from the digestive system; nervous and endocrine coordinate all others. Practical examples: ruminant feeding programmes designed for rumen fermentation versus poultry rations with no roughage; reproductive management requiring knowledge of the reproductive tract and hormone cycles; health procedures (injections, catheterisation) performed at anatomically correct sites.

12. Value-added response: The most practically important integrative principle is that the digestive anatomy of the species determines its nutritional requirements. A ruminant with a functional rumen can derive energy from cellulose that a monogastric cannot, making fibre a resource rather than a waste product. Conversely, the rumen population can be destabilised by inappropriate feeding: excess rapidly fermentable carbohydrate causes acidosis; protein-rich lush pasture causes bloat. Detailed knowledge of rumen anatomy and fermentation physiology is therefore the prerequisite for both ration formulation and nutritional disease diagnosis in ruminants.

13. Basic response: Three planes: median (equal left and right halves), transverse (cranial and caudal portions), dorsal (dorsal and ventral portions). Directional terms: cranial/caudal, dorsal/ventral, medial/lateral, proximal/distal, palmar/plantar. Thoracic: lungs bilateral lateral to heart, heart medial in mediastinum, trachea dorsal to heart, oesophagus dorsal to trachea. Abdominal ruminant: rumen large left lateral, omasum and abomasum right side, liver right cranial, spleen left. Pelvic: rectum dorsal, bladder ventral, uterus and ovaries in females between rectum and bladder.
14. Value-added response: Mastery of directional terms is safety-critical in clinical practice. A producer describing the location of an abnormal swelling to a distant veterinarian must be able to specify whether it is cranial or caudal to the navel, medial or lateral to the stifle, dorsal or ventral to the last rib. Without this shared vocabulary, a telephone triage call cannot reliably determine whether an animal needs immediate veterinary attention. These communication skills have direct economic value in livestock systems where veterinary visits are expensive and infrequent, making anatomical vocabulary a productive farm management tool, not an academic formality.

15. Basic response: Animal cell: cell membrane (selective permeability), nucleus (DNA, cell control), cytoplasm (fluid matrix), mitochondria (ATP generation), rough ER (protein synthesis), smooth

ER (lipid synthesis), ribosomes (protein synthesis), Golgi apparatus (packaging and secretion), lysosomes (intracellular digestion). Four tissue types: epithelial (surface covering, tightly packed cells), connective (support, cells in extracellular matrix), muscle (contraction, three subtypes), nervous (impulse conduction, neurons and glia). Hierarchical organisation: cell to tissue to organ (two or more tissue types) to organ system to whole animal. Viral liver example: hepatocyte destruction causes hepatitis (tissue), liver failure (organ), metabolic collapse (system), death or production loss (whole animal).

16. Value-added response: The four tissue types are not abstract categories but the building blocks of diagnostic thinking. Every clinical sign maps to a tissue: fever from inflammation in connective tissue, diarrhoea from disrupted epithelial absorption in the intestine, weakness from muscle degeneration, convulsions from neurological disturbance. Placing clinical signs into their tissue-level context transforms symptom observation into mechanistic diagnostic reasoning. This is the intellectual bridge between anatomy knowledge and clinical competence, and why anatomy and physiology are the gateway courses to all applied animal science disciplines.

Answers to Pilot Questions [Series 1]

Part 1.1: Introduction to Animal Anatomy

1. Anatomy is the science of structure; physiology is the science of function; they are studied together because structure determines function and function depends on structure. Understanding the rumen's four-chambered anatomy explains why it can ferment cellulose; understanding the nephron's tubular structure explains kidney filtration. Separating the two creates an artificial division that makes both harder to apply in practical animal management.
2. Gross anatomy studies structures visible to the naked eye such as organs, bones, and blood vessels. Histology is the microscopic study of tissues and their cellular organisation under the light or electron microscope. Cytology is the microscopic study of individual cells and their organelles; it is the smallest-scale subdivision and provides the basis for understanding how tissues perform their functions.
3. In ruminants, the multi-chambered fermentation stomach (rumen, reticulum, omasum, abomasum) allows microbial digestion of cellulose and hemicellulose from forages, generating volatile fatty acids as the primary energy source; rations must therefore include large proportions of roughage and the concentrate-to-roughage ratio must be controlled to avoid acidosis. In poultry

there is no rumen; the gizzard provides mechanical grinding but no fermentation, so carbohydrate must be directly digestible and dietary fibre is minimised.

4. Any seven: skeletal (structural support and lever system for movement); muscular (locomotion and posture); integumentary (protection against environment and thermoregulation); digestive (ingestion, digestion, absorption, and waste elimination); cardiovascular (transport of blood, oxygen, and nutrients); respiratory (gas exchange between blood and atmosphere); urinary (excretion of metabolic waste and fluid balance); nervous (coordination of body activities); endocrine (hormonal regulation of metabolism and reproduction); reproductive (production of offspring).
5. Anaemia reduces the oxygen-carrying capacity of blood; the cardiovascular system compensates by increasing heart rate, stressing the cardiac muscle; reduced oxygen delivery to all tissues impairs mitochondrial ATP production; muscle tissue receives less oxygen, reducing exercise tolerance; digestive organ function is impaired, reducing nutrient absorption; immune cells require energy for their activity, so immune defences weaken; reproductive hormone synthesis requires normal metabolic function, so fertility declines. One cellular problem propagates through all body systems.

Part 1.2: Anatomical Planes, Directions, and Regions

1. Median plane (midsagittal): through the midline from head to tail, dividing the body into equal left and right halves. Transverse plane (cross-sectional): at right angles to the long axis, dividing the body into cranial and caudal portions. Dorsal plane (horizontal or frontal): parallel to the dorsal surface, dividing the body into dorsal (upper) and ventral (lower) portions.
2. A median section is a cut through the median plane revealing midline structures such as the nasal septum, vertebral bodies, and centrally positioned organs by dividing the body into exactly equal left and right halves. A transverse section (cross-section) is a cut at right angles to the long axis revealing the circular or oval internal architecture of the body or an organ at a specific level; for example, a cross-section through the midabdomen shows the rumen on the left, intestines, and vertebrae dorsally.
3. Cranial: towards the head (the thorax is cranial to the abdomen). Caudal: towards the tail (the pelvis is caudal to the abdomen). Dorsal: towards the back or upper surface (the spine is dorsal to the heart). Ventral: towards the belly (the sternum is ventral to the heart). Medial: towards the

median plane (the trachea is medial to the lungs). Lateral: away from the median plane (the lungs are lateral to the heart).

4. Proximal means nearer to the point of attachment of the limb to the trunk; distal means farther from it. In the forelimb: the humerus is the most proximal bone; the digits (hooves) are the most distal structures. These terms allow unambiguous description of limb structures regardless of the animal's position or the observer's viewpoint.
5. Any four with clinical significance: neck (cervical region): site of jugular venipuncture for blood sampling and intravenous medication; withers: standard point for measuring animal height; flank (lateral abdominal wall between last rib and hip): site of rumen auscultation, left flank laparotomy for displaced abomasum, and rumen trocarisation for bloat; croup (sacral and gluteal region): site of tailhead epidural injection and subcutaneous fat scoring.

Part 1.3: Body Cavities and Their Contents

1. Right and left lungs (each within its pleural cavity), heart (within the pericardium in the mediastinum), trachea, oesophagus, thoracic duct, aorta and great vessels (pulmonary artery, pulmonary veins, cranial and caudal venae cavae), phrenic nerves (innervating the diaphragm), vagus nerves (passing to the abdominal organs), and the diaphragm at the caudal boundary.
2. The diaphragm is a dome-shaped sheet of skeletal muscle attached peripherally to the ribs, sternum, and lumbar vertebrae. At rest it is dome-shaped with the dome protruding cranially. When the respiratory centres stimulate contraction of its muscle fibres, the dome flattens and moves caudally, increasing the volume of the thoracic cavity. The increased volume reduces intrathoracic pressure below atmospheric pressure, causing air to flow through the trachea and bronchi into the lungs until pressures equalise.
3. In a ruminant, the abdominal cavity is dominated by the four-chambered stomach: the rumen (very large, occupying the entire left side and much of the ventral abdomen), reticulum (cranioventral near the diaphragm), omasum (right of midline, cranial), and abomasum (right ventral). The liver is in the right cranial abdomen; the spleen is on the left attached to the rumen wall; kidneys are retroperitoneal dorsally. In a monogastric (pig, horse), a single-chambered stomach occupies the cranial left abdomen and the intestines fill more of the cavity.
4. Serous membranes are thin smooth tissue sheets lining body cavities and covering their organs; they secrete serous fluid that lubricates the surfaces and allows organs to move against each other and against the body wall without friction during breathing, digestion, and locomotion. Two

layers: the parietal layer lines the inner wall of the body cavity; the visceral layer covers the outer surface of the organs; the thin film of serous fluid occupies the potential space between them.

5. Pleura: lines the thoracic cavity (parietal pleura) and covers the lungs (visceral pleura); pleural cavity between them; inflammation is pleuritis causing painful breathing and possible pleural effusion. Pericardium: encloses the heart (parietal pericardium outer sac, visceral pericardium covering heart surface); pericardial cavity between them; inflammation is pericarditis, which follows bacterial infection in traumatic pericarditis from hardware disease in cattle. Peritoneum: lines abdominal and pelvic cavities and covers abdominal organs; peritoneal cavity between layers; inflammation is peritonitis, caused by foreign body migration through the reticulum in traumatic reticuloperitonitis.

Part 1.4: Cells, Tissues, and Organs

1. Any five: nucleus (contains DNA and controls cell activity and reproduction); mitochondrion (generates ATP by aerobic respiration); rough endoplasmic reticulum (protein synthesis for secretion, studded with ribosomes); ribosomes (sites of protein synthesis from mRNA template); Golgi apparatus (packages and processes proteins and lipids for secretion or intracellular use); lysosome (contains digestive enzymes that break down waste material, worn organelles, and engulfed particles).
2. Epithelial: tightly packed cells with little extracellular material; covers surfaces, lines hollow organs, and forms glands; functions in protection, secretion, and absorption. Connective: cells embedded in abundant extracellular matrix of fibres and ground substance; functions in support, connection, transport, and storage. Muscle: elongated cells packed with contractile proteins; functions in movement by contraction. Nervous: neurons with long extensions plus supporting neuroglial cells; functions in receiving stimuli and coordinating body responses.
3. Simple epithelium has a single layer of cells all in contact with the basement membrane; found lining the small intestine (simple columnar epithelium for absorption) and the alveoli of the lung (simple squamous for gas exchange). Stratified epithelium has multiple cell layers with only the deepest layer contacting the basement membrane; found covering the skin (stratified squamous keratinised, for mechanical protection and water retention) and lining the oesophagus (stratified squamous non-keratinised).
4. An organ is a structure of two or more tissue types organised to perform a specific function. Example: the heart contains cardiac muscle tissue (the myocardium, which contracts to pump

blood), fibrous connective tissue (the cardiac skeleton providing structural support and valve attachment), epithelial tissue (endocardium lining the chambers and epicardium covering the outer surface), and nervous tissue (the conduction system of the sinoatrial and atrioventricular nodes coordinating the heartbeat).

5. Hepatocytes perform essential metabolic functions: they produce albumin (maintaining blood osmotic pressure), clotting factors (for haemostasis), bile (for fat digestion), detoxify drugs and toxins, convert ammonia to urea, and store glycogen. Viral destruction of hepatocytes impairs all these: albumin falls causing oedema; clotting factors are deficient causing haemorrhage; bile production falls impairing fat absorption; detoxification fails accumulating toxins. Consequences cascade from hepatocyte death (cell level) through hepatitis (tissue), liver failure (organ), metabolic and haematological collapse (system), to death or severe production loss (whole animal).

References and Attributions [Series 1]

Textual References (Books and External Sources)

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- Reece, W. O. (2015). Dukes' physiology of domestic animals (13th ed.). Wiley-Blackwell.
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- Getty, R. (Ed.). (1975). Sisson and Grossman's anatomy of domestic animals (5th ed.). W. B. Saunders.
- FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable agriculture. FAO.

Figures, Plates, Tables, and Boxes

- Figure 1.1: Anatomy and physiology subdivisions diagram Attribution: AI generated using prompt "Generate a diagram showing the subdivisions of anatomy and physiology and their

relationship to farm animal production." Suggested OER search string: "anatomy physiology subdivisions gross histology farm animal OER diagram".

- Figure 1.2: Anatomy and physiology importance diagram Attribution: AI generated using prompt "Generate a diagram showing anatomy and physiology connected to nutrition, reproduction, health, production management, and product quality." Suggested OER search string: "anatomy physiology importance animal production disciplines OER diagram".
- Figure 1.3: Body systems network diagram Attribution: AI generated using prompt "Generate a network diagram showing the eleven major body systems of farm animals and their primary functional interconnections." Suggested OER search string: "body systems farm animals network interconnections diagram OER".
- Figure 1.4: Anatomical planes of the cow Attribution: AI generated using prompt "Generate a three-dimensional diagram of a cow showing the median, transverse, and dorsal anatomical planes with labels." Suggested OER search string: "anatomical planes cow median transverse dorsal diagram OER".
- Figure 1.5: Directional terms lateral view of cow Attribution: AI generated using prompt "Generate a labelled lateral view of a cow showing all standard directional anatomical terms with arrows." Suggested OER search string: "directional terms cow anatomy cranial caudal dorsal ventral OER diagram".
- Figure 1.6: Topographical regions cattle sheep poultry Attribution: AI generated using prompt "Generate a three-panel diagram showing labelled topographical regions of cattle, sheep, and a laying hen in lateral view." Suggested OER search string: "topographical regions cattle sheep laying hen labelled OER diagram".
- Figure 1.7: Bovine thoracic cavity cross-section Attribution: AI generated using prompt "Generate a cross-section diagram of the bovine thoracic cavity showing the lungs, heart, pericardium, mediastinum, trachea, and diaphragm." Suggested OER search string: "bovine thoracic cavity cross-section lungs heart pericardium OER".
- Figure 1.8: Bovine abdominal cavity organs Attribution: AI generated using prompt "Generate a diagram of the bovine abdominal cavity showing major organs from left and right lateral views." Suggested OER search string: "bovine abdominal cavity rumen omasum abomasum liver organs OER diagram".
- Figure 1.9: Serous membranes diagram Attribution: AI generated using prompt "Generate a cross-section diagram showing parietal and visceral layers of pleura, pericardium, and peritoneum with serous cavities between them." Suggested OER search string: "serous membranes pleura pericardium peritoneum parietal visceral OER".

- Figure 1.10: Animal cell organelles diagram Attribution: AI generated using prompt "Generate a labelled diagram of a typical animal cell showing the cell membrane, nucleus, mitochondria, endoplasmic reticulum, Golgi apparatus, and lysosomes." Suggested OER search string: "animal cell organelles labelled diagram nucleus mitochondria OER".
- Figure 1.11: Four tissue types diagrams Attribution: AI generated using prompt "Generate a four-panel diagram showing the four tissue types: simple columnar epithelium, fibrous connective tissue, skeletal muscle, and a neuron with key features labelled." Suggested OER search string: "four tissue types epithelial connective muscle nervous diagrams OER".
- Figure 1.12: Biological organisation hierarchy Attribution: AI generated using prompt "Generate a vertical hierarchy diagram showing the levels of biological organisation from chemical molecules through cell, tissue, organ, and organ system to the whole farm animal, with examples." Suggested OER search string: "biological organisation hierarchy cell tissue organ system farm animal OER".

Course code: AGE 204

Course title: Anatomy and Physiology of Farm Animals

Course credit load: 2 Units

Series 2: Skeletal Structures, Joints, and Muscular Systems of Farm Animals

- **Part 2.1: The Skeletal System**
  - Sub Part 2.1.1: Functions and divisions of the skeleton
  - Sub Part 2.1.2: Bone structure and types
  - Sub Part 2.1.3: Major bones of the axial and appendicular skeleton
- **Part 2.2: Joints of Farm Animals**
  - Sub Part 2.2.1: Classification and structure of joints
  - Sub Part 2.2.2: Major joints and their movements
  - Sub Part 2.2.3: Common joint conditions in farm animals
- **Part 2.3: The Muscular System of Mammals**
  - Sub Part 2.3.1: Types and properties of muscle tissue
  - Sub Part 2.3.2: Major muscle groups and their actions
  - Sub Part 2.3.3: Muscle contraction and energy supply
- **Part 2.4: The Muscular System of Avian Species**
  - Sub Part 2.4.1: Structural differences between avian and mammalian muscle
  - Sub Part 2.4.2: Major muscle groups of poultry
  - Sub Part 2.4.3: Flight versus non-flight musculature and meat quality

Introduction

The skeletal and muscular systems together form the locomotor apparatus of farm animals. Bones provide the rigid framework and levers on which muscles act; joints allow controlled movement between bones; and muscles generate the forces that produce locomotion, posture, and the movement of organs. Understanding the structure of bones, the classification of joints, and the arrangement of muscle groups is essential for assessing conformation, interpreting lameness, evaluating carcass composition, and managing musculoskeletal health.

The aim of this Series is to describe the skeletal system of farm animals, the classification and major joints, the muscular system of mammals, and the distinctive features of avian musculature. We shall begin with the functions and structure of bone, cover the major skeletal bones, examine joints and their movements, then study the mammalian muscular system, and conclude with avian muscle organisation and its relevance to poultry meat production.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 2.1** describe the functions and divisions of the skeleton and explain bone structure and types (Linked to Part 2.1),
- **SLO 2.2** identify the major bones of the axial and appendicular skeleton in farm animals (Linked to Part 2.1),
- **SLO 2.3** classify joints and describe the structure and movements of synovial joints (Linked to Part 2.2),
- **SLO 2.4** name the major joints of farm animals and describe common joint conditions (Linked to Part 2.2),
- **SLO 2.5** describe the three types of muscle tissue and explain the properties of skeletal muscle (Linked to Part 2.3),
- **SLO 2.6** identify the major muscle groups of farm animals and describe their actions (Linked to Part 2.3),
- **SLO 2.7** explain the mechanism of muscle contraction and the role of ATP (Linked to Part 2.3), and

- **SLO 2.8** describe the distinctive features of avian musculature and explain how muscle type relates to meat quality in poultry (Linked to Part 2.4).

2.1 The Skeletal System

2.1.1 Functions and divisions of the skeleton

The skeleton performs five main functions: support (providing the structural framework of the body), protection (enclosing the brain, spinal cord, and thoracic organs), movement (providing levers for muscle action), mineral storage (especially calcium and phosphorus), and blood cell production (haematopoiesis in red bone marrow). The skeleton is divided into the axial skeleton (skull, vertebral column, ribs, and sternum) and the appendicular skeleton (the forelimbs, hindlimbs, and their girdles).

In farm animals the skeleton must support considerable body weight and withstand the forces of locomotion and production. The number of vertebrae varies by species and region; cattle have 7 cervical, 13 thoracic, 6 lumbar, 5 sacral, and 18 to 20 coccygeal vertebrae. Poultry have a fused synsacrum and pygostyle replacing the free lumbar, sacral, and caudal vertebrae of mammals, reflecting adaptation for flight and bipedal stance.

Fill in the blank: The skeleton is divided into the _____ skeleton (skull, vertebral column, ribs, sternum) and the appendicular skeleton (limbs and girdles).

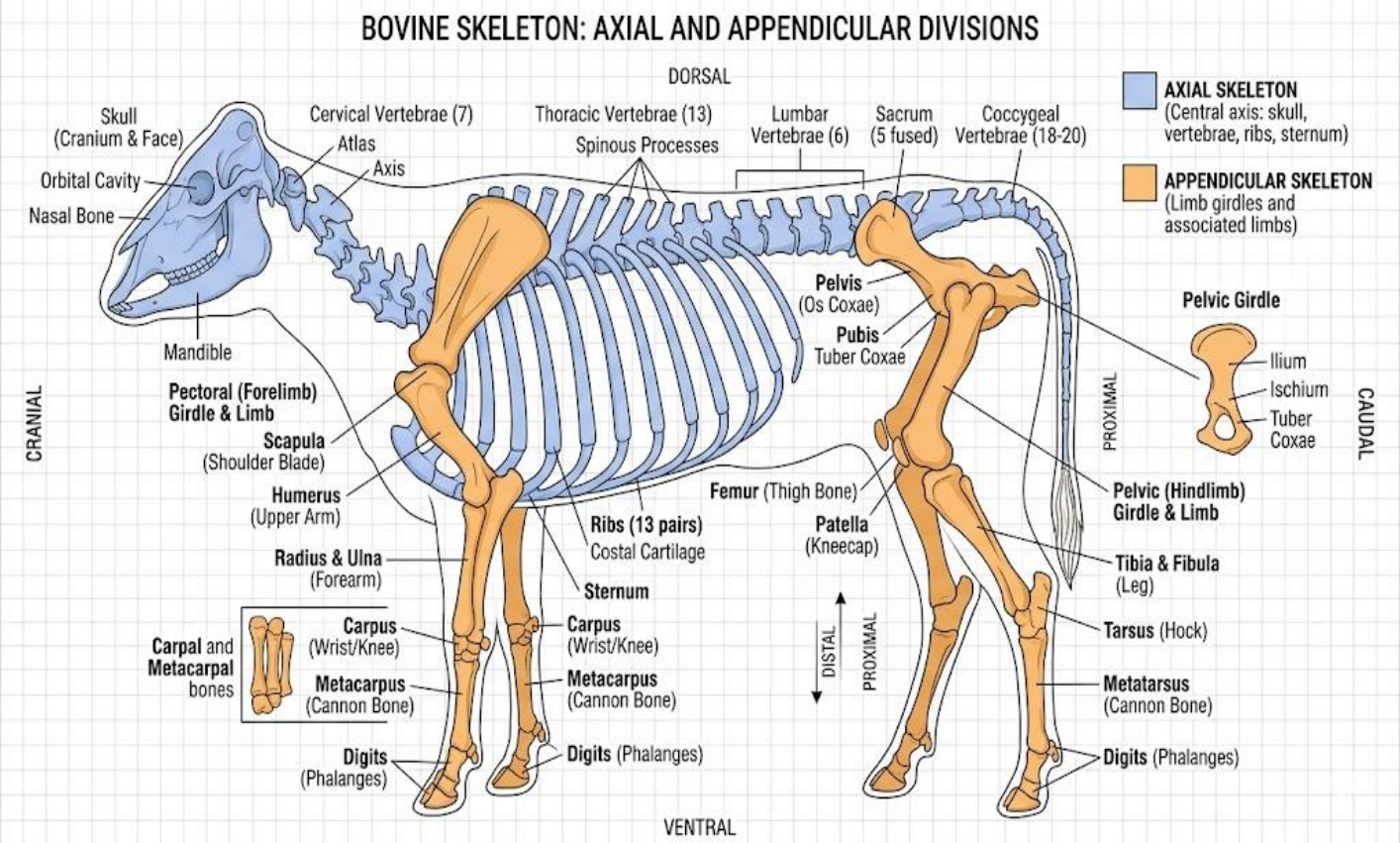

Figure 2.1: Labelled diagram of the bovine skeleton showing axial and appendicular divisions

2.1.2 Bone structure and types

A long bone consists of a shaft (diaphysis) of compact bone surrounding a medullary cavity containing yellow marrow, capped at each end by epiphyses of cancellous (spongy) bone containing red marrow. The outer surface is covered by periosteum (a fibrous layer that anchors tendons and supports bone repair), and the inner cavity is lined by endosteum. Compact bone is dense and strong; cancellous bone is light and porous, allowing marrow function.

Bones are classified by shape: long bones (humerus, femur, metacarpus) act as levers for locomotion; short bones (carpals, tarsals) absorb concussion; flat bones (scapula, pelvic bones, skull plates) protect organs or provide broad muscle attachment surfaces; irregular bones (vertebrae) have complex shapes serving mixed functions; and sesamoid bones (patella, navicular bone) reduce friction at tendons and joints. Bone grows in length at the epiphyseal growth plate, which closes at skeletal maturity.

Fill in the blank: The shaft of a long bone is called the _____ and consists of compact bone surrounding a medullary cavity; the ends are called epiphyses and consist of cancellous bone.

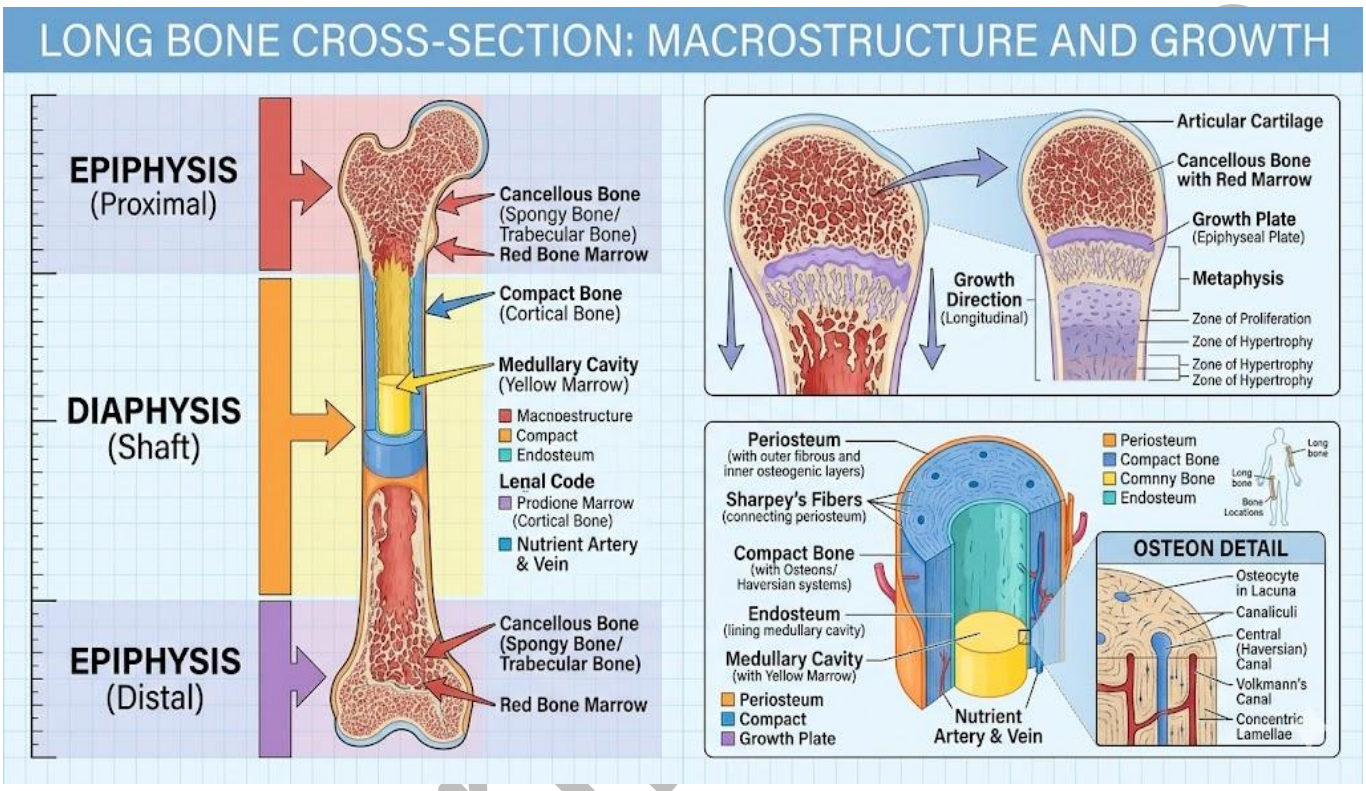

Figure 2.2: Cross-section diagram of a long bone showing its structural components

2.1.3 Major bones of the axial and appendicular skeleton

In the axial skeleton, the skull houses the brain and forms the orbits, nasal cavity, and dental arcades. The vertebral column protects the spinal cord and provides attachment for muscles of the back and neck. The thoracic cage (13 pairs of ribs in cattle, 14 in pigs, 7 in poultry) encloses and protects the heart and lungs and participates in breathing movements. The sternum provides ventral attachment for the ribs and the pectoral muscles.

In the appendicular skeleton, the forelimb consists of the scapula, humerus, radius, ulna, carpus (knee in cattle), metacarpus (cannon bone), and digits. The hindlimb consists of the pelvis (ilium, ischium, pubis), femur, tibia, fibula, tarsus (hock), metatarsus, and digits. Cattle have two main digits (digits III and IV) with dewclaws (digits II and V). Horses are monodactyl (single digit), and pigs are tridactyl with functional digits III and IV.

Fill in the blank: Cattle have _____ main weight-bearing digits on each foot (digits III and IV) plus vestigial dewclaws representing digits II and V.

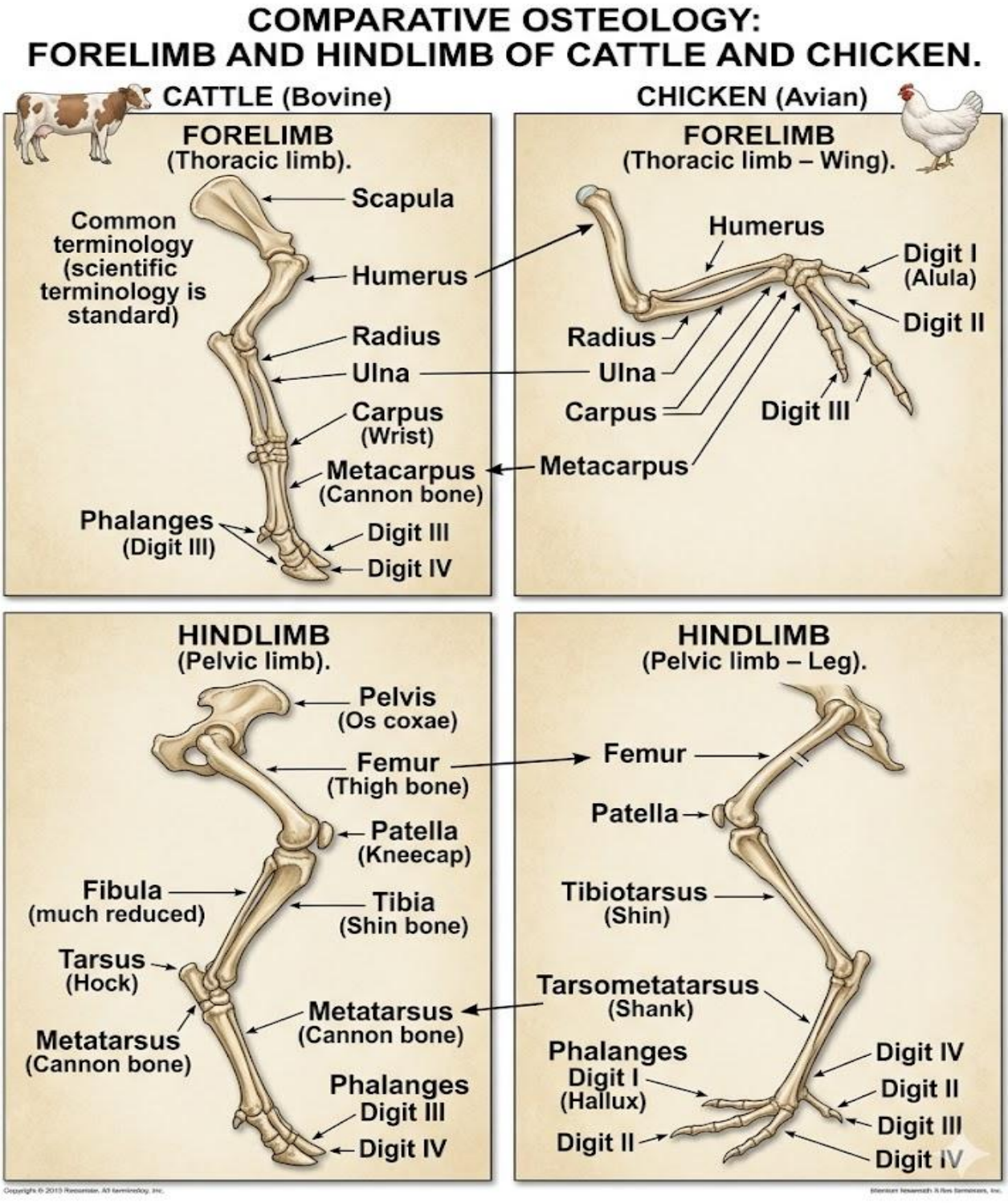

Figure 2.3: Diagram comparing the forelimb and hindlimb bones of cattle and a chicken

Pilot questions 2.1

1. State the five functions of the skeleton.
2. Distinguish between the axial and appendicular skeleton and give two examples of bones in each.
3. Describe the structure of a long bone naming five structural components.
4. Name and classify five types of bone by shape and give one example of each.
5. List the bones of the bovine forelimb from proximal to distal.

2.2 Joints of Farm Animals

2.2.1 Classification and structure of joints

Joints are classified by their degree of movement. Fibrous joints (synarthroses) are immovable; bones are united by fibrous connective tissue with no cavity. Examples include the sutures of the skull and the teeth in their sockets. Cartilaginous joints (amphiarthroses) allow slight movement; bones are connected by fibrocartilage or hyaline cartilage. Examples include the intervertebral discs and the pubic symphysis.

Synovial joints (diarthroses) are freely movable and are the most important joints for locomotion. They consist of: articular cartilage covering the bone ends, a joint capsule of fibrous tissue lined by synovial membrane, and synovial fluid secreted by the membrane to lubricate and nourish the articular cartilage. Many synovial joints are reinforced by ligaments (fibrous bands connecting bone to bone) and may contain intra-articular structures such as menisci (the stifle joint in cattle).

Fill in the blank: Synovial joints are freely movable and are lubricated by _____ fluid secreted by the synovial membrane lining the joint capsule.

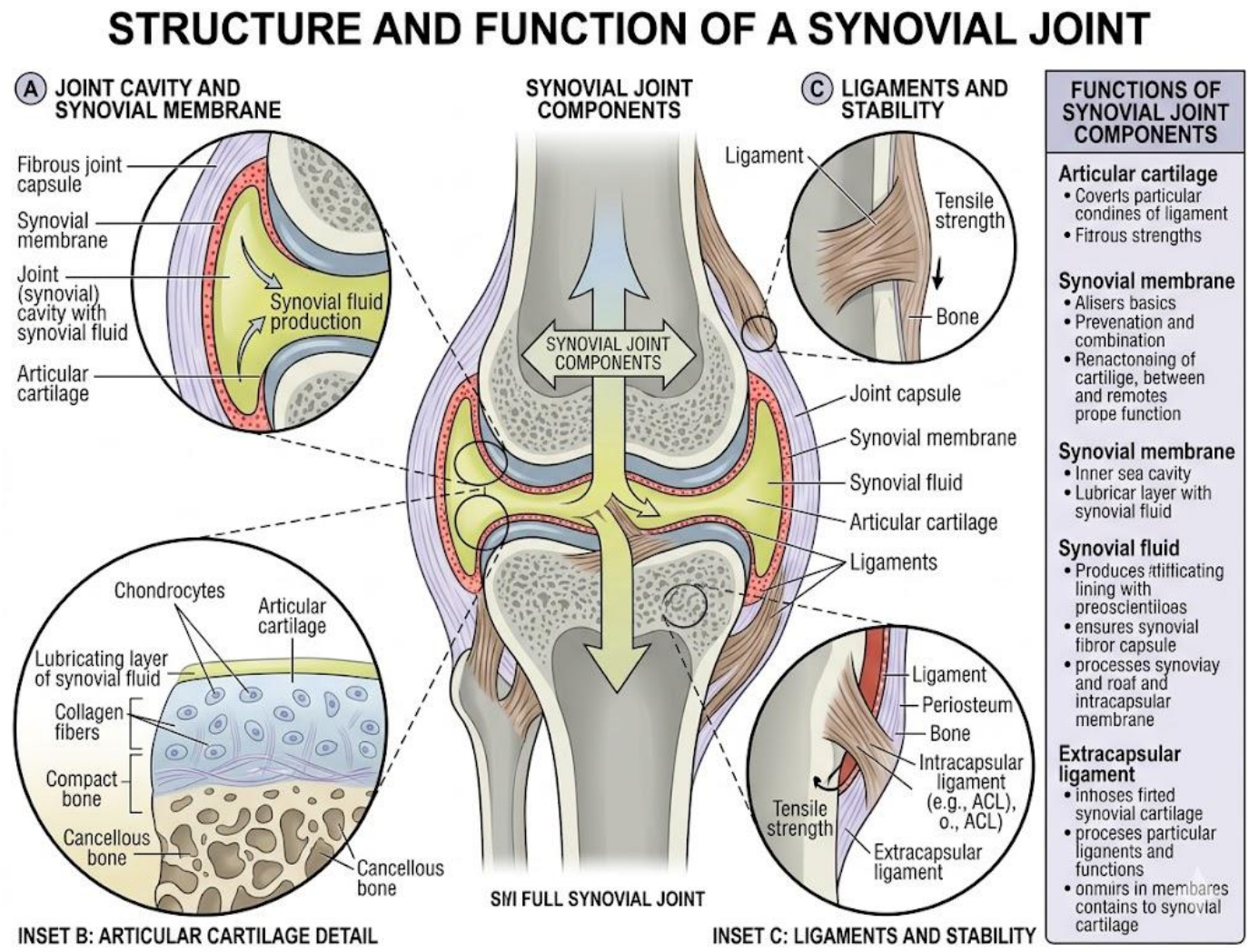

Figure 2.4: Cross-section diagram of a synovial joint showing its structural components

2.2.2 Major joints and their movements

The major joints of farm animals and their movements include: the shoulder (scapulohumeral joint, a ball-and-socket allowing flexion, extension, and some rotation), the elbow (humeroulnar, a hinge joint allowing flexion and extension), the carpus (a compound joint allowing flexion and extension with limited rotation), the fetlock (metacarpophalangeal, a hinge joint critical for weight bearing and shock absorption in cattle and horses), and the stifle (femorotibial and femoropatellar joints, equivalent to the human knee, a complex joint with cruciate ligaments and menisci).

In the hindlimb, the hip joint (coxofemoral, ball-and-socket) allows the greatest range of movement. The hock (tarsocrural joint) is a hinge joint equivalent to the human ankle. Spinal joints between adjacent vertebrae allow small movements that sum to produce the overall flexibility of the vertebral column. In poultry, the major joints include the shoulder, elbow, wrist (in the wing), hip, stifle, and hock; the intertarsal joint of birds is equivalent to the mammalian ankle.

Fill in the blank: The _____ joint (femorotibial and femoropatellar joints) is equivalent to the human knee, contains cruciate ligaments and menisci, and is one of the most complex joints in farm animals.

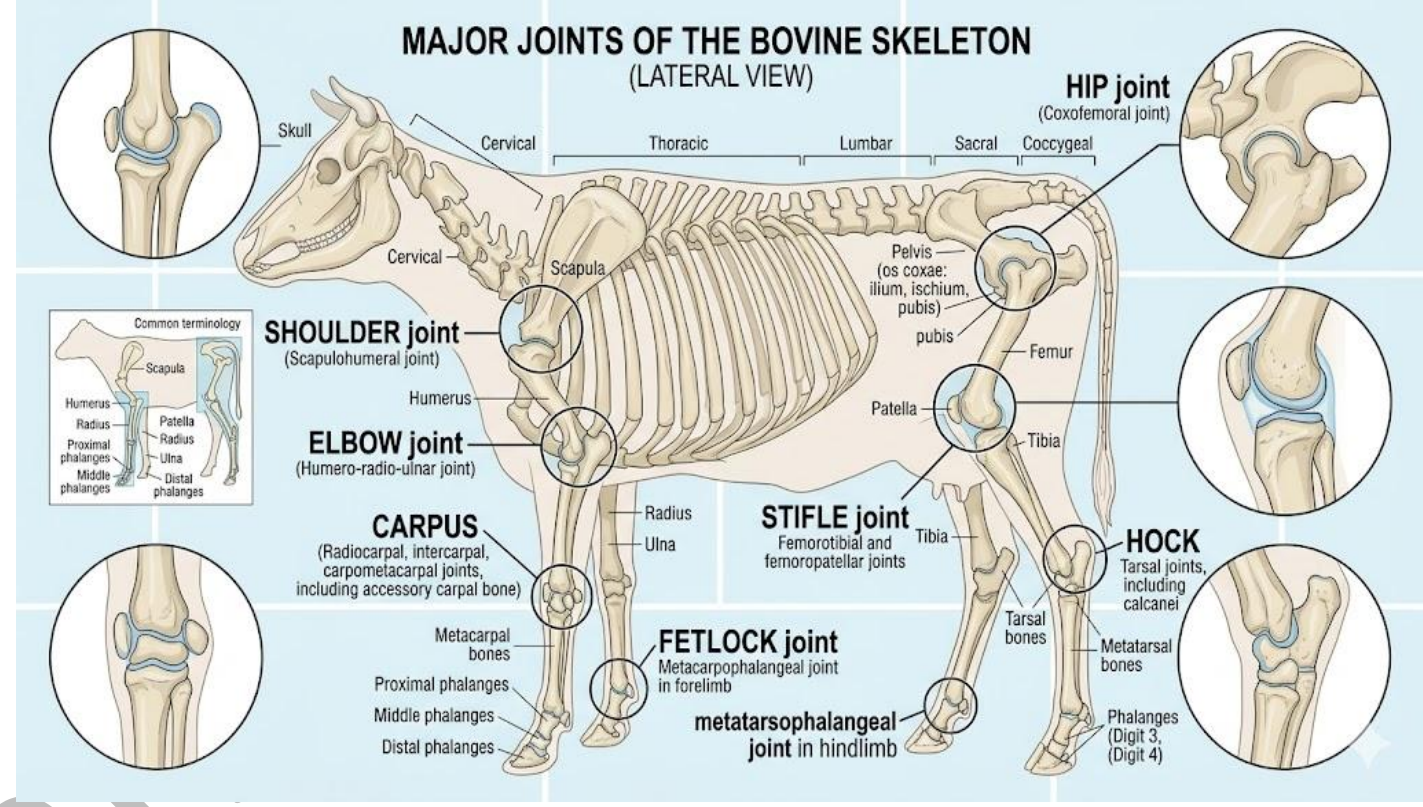

Figure 2.5: Diagram showing the major joints of a cow labelled on a lateral view skeleton

2.2.3 Common joint conditions in farm animals

Arthritis is inflammation of a joint causing pain, swelling, heat, and reduced range of movement. Septic arthritis (joint ill) is caused by bacterial infection; it is particularly common in newborn

calves and lambs when bacteria enter through the navel or wounds. The stifle, hock, and fetlock are the most frequently affected joints. Osteochondrosis dissecans (OCD) is a developmental joint disease in which articular cartilage fails to ossify correctly, leading to cartilage flaps and joint effusion; it is most common in rapidly growing pigs and horses.

Foot rot (infectious pododermatitis) affects the interdigital skin and underlying tissues of the digit, causing severe lameness in cattle; it is caused by Fusobacterium necrophorum and is favoured by wet, muddy conditions. Laminitis is inflammation of the sensitive laminae of the hoof, causing severe lameness in cattle, horses, and goats; it is associated with grain overload and metabolic disease. Prevention relies on good housing, hoof trimming, and balanced nutrition.

Fill in the blank: _____ arthritis in newborn calves and lambs is caused by bacterial infection entering through the navel or wounds, most frequently affecting the stifle, hock, and fetlock joints.

Condition	Cause	Species	Affected Joint
Septic arthritis	Bacterial infection (often via wounds or systemic spread)	Cattle, sheep, goats, horses	Commonly stifle, hock, fetlock
Osteochondritis dissecans (OCD)	Developmental cartilage defect leading to joint lesions	Horses, cattle	Predominantly stifle, hock
Foot rot	Bacterial infection (Fusobacterium necrophorum, Dichelobacter nodosus)	Cattle, sheep, goats	Interdigital space, distal joints of the foot
Laminitis	Inflammation of laminae due to metabolic, dietary, or mechanical stress	Cattle, horses	Hoof (distal phalanx attachment)

Box 2.1: Key joint conditions in farm animals with their causes and affected species

Pilot questions 2.2

1. Classify joints by degree of movement and give one example of each class.
2. Name the five structural components of a synovial joint.
3. State the type of movement at the shoulder, elbow, and stifle joints.

4. Explain what septic arthritis is and state the most common route of infection in newborn ruminants.
5. Describe laminitis and state two predisposing factors.

2.3 The Muscular System of Mammals

2.3.1 Types and properties of muscle tissue

Three types of muscle tissue exist in mammals. Skeletal muscle is attached to bone via tendons, is under voluntary control, is striated (shows cross-striations under the microscope from the regular arrangement of contractile proteins), and is responsible for locomotion and posture. Cardiac muscle forms the wall of the heart, is involuntary, striated, and self-stimulating through its own conduction system. Smooth muscle is found in the walls of hollow organs (stomach, intestines, blood vessels, uterus), is involuntary and non-striated, and controls the diameter and movement of those organs.

Skeletal muscle fibres are classified by their metabolic and contractile properties. Type I fibres (slow-twitch, red fibres) contract slowly, are highly resistant to fatigue, rely on aerobic metabolism, and are rich in myoglobin (giving red colour); they support sustained activity such as posture maintenance. Type II fibres (fast-twitch, white fibres) contract rapidly, fatigue quickly, rely on anaerobic glycolysis, and contain less myoglobin; they produce powerful short-duration contractions for locomotion and escape responses.

Fill in the blank: Type I skeletal muscle fibres are called slow-twitch fibres and are resistant to _____, while Type II fast-twitch fibres contract rapidly but fatigue quickly.

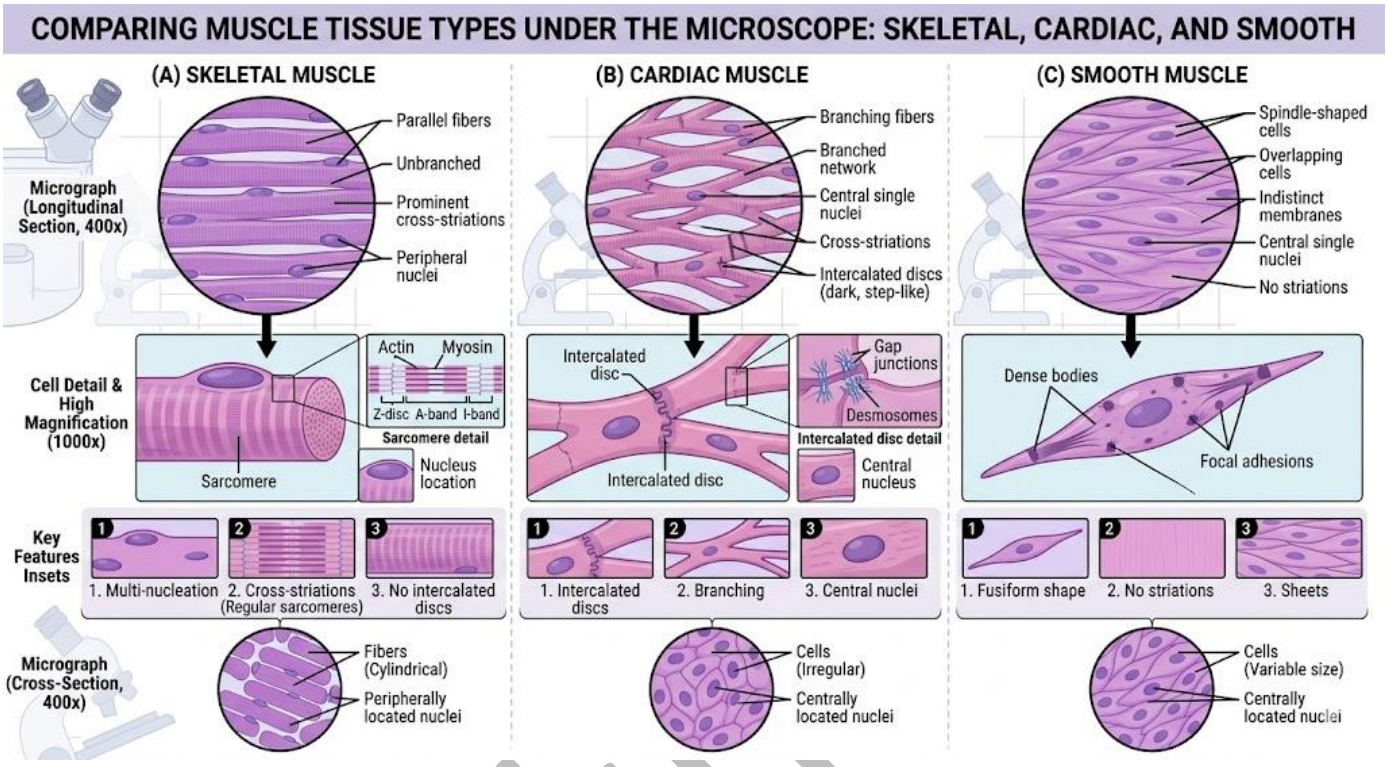

Figure 2.6: Diagram comparing the three muscle tissue types under the microscope

2.3.2 Major muscle groups and their actions

The muscles of farm animals are organised into functional groups by location and action. The epaxial muscles (dorsal to the vertebral column: longissimus dorsi, semispinalis, multifidus) extend and stabilise the back and are the primary source of high-value loin meat in cattle and pigs. The hypaxial muscles (ventral to the vertebral column: psoas major, psoas minor, iliacus) flex the lumbar spine and are important in pelvic limb protraction. The gluteal muscles (gluteus medius, superficialis, and profundus) are the main extensors of the hip joint.

In the forelimb, the major muscles include the trapezius and serratus ventralis (supporting the thorax between the forelimbs), the triceps brachii (extending the elbow), and the digital flexors and extensors (controlling the digits). In the hindlimb, the quadriceps femoris (extending the stifle), biceps femoris and semitendinosus (flexing the stifle and extending the hip), and the gastrocnemius (extending the hock) are the most functionally important. These muscle groups are also the primary determinants of carcass yield and lean meat content.

Fill in the blank: The _____ dorsi muscle runs the length of the back along the vertebral column and is the primary source of high-value loin cuts in the cattle and pig carcass.

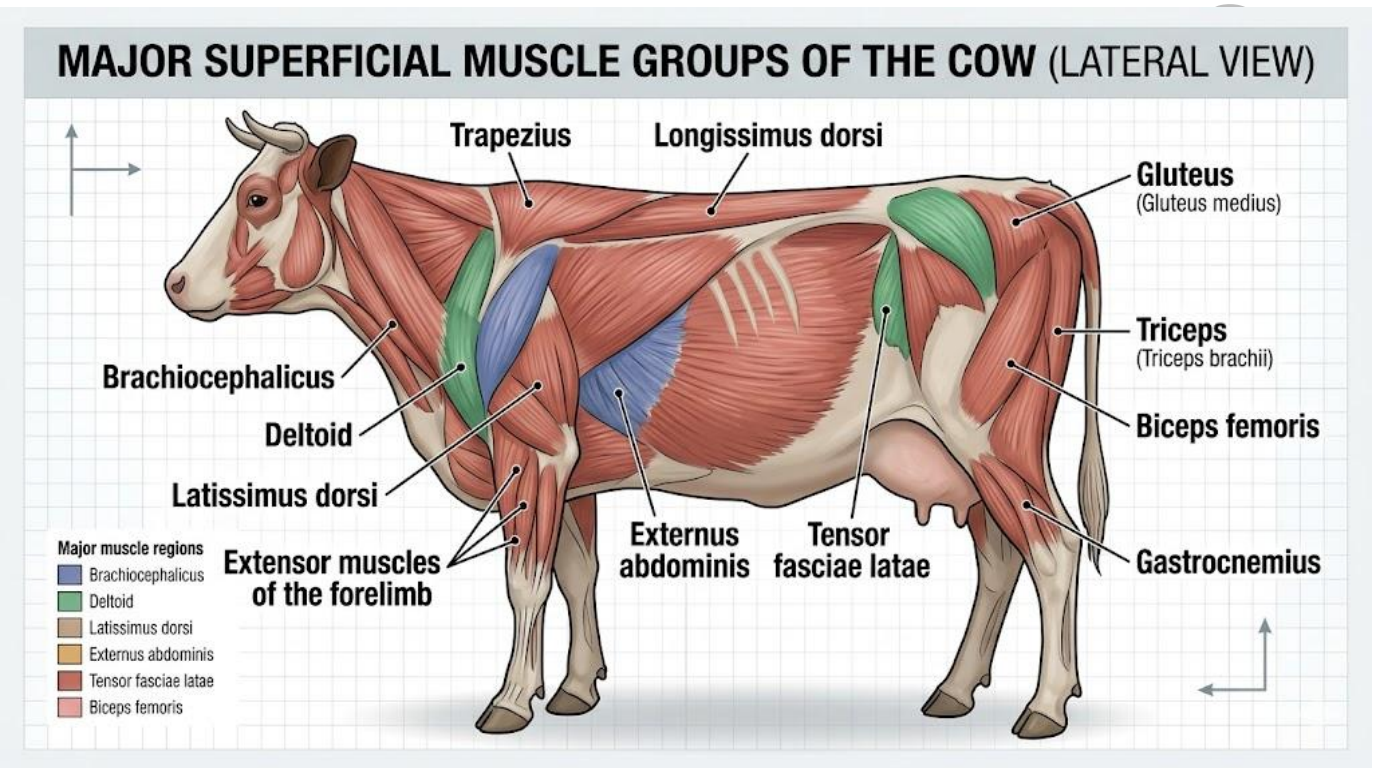

Figure 2.7: Diagram showing the major superficial muscle groups of a cow in lateral view

2.3.3 Muscle contraction and energy supply

Muscle contraction is explained by the sliding filament theory: the contractile unit of skeletal muscle is the sarcomere, which contains interdigitating thick filaments (myosin) and thin filaments (actin). When the muscle is activated by a nerve impulse, calcium ions are released from the sarcoplasmic reticulum, triggering the binding of myosin heads to actin and the power stroke that slides thin filaments past thick filaments, shortening the sarcomere and the whole muscle.

Energy for contraction is supplied as ATP. At the onset of contraction, immediate ATP comes from creatine phosphate stores. During sustained activity, aerobic respiration of glucose and fatty acids in mitochondria provides the majority of ATP for Type I fibres. When oxygen supply is insufficient, anaerobic glycolysis generates ATP rapidly but produces lactic acid, causing muscle

fatigue. After slaughter, continued anaerobic glycolysis converts glycogen to lactic acid, lowering muscle pH and converting muscle to meat through rigor mortis.

Fill in the blank: Muscle contraction is explained by the _____ filament theory, in which myosin heads bind to actin and generate a power stroke that slides thin filaments past thick filaments, shortening the sarcomere.

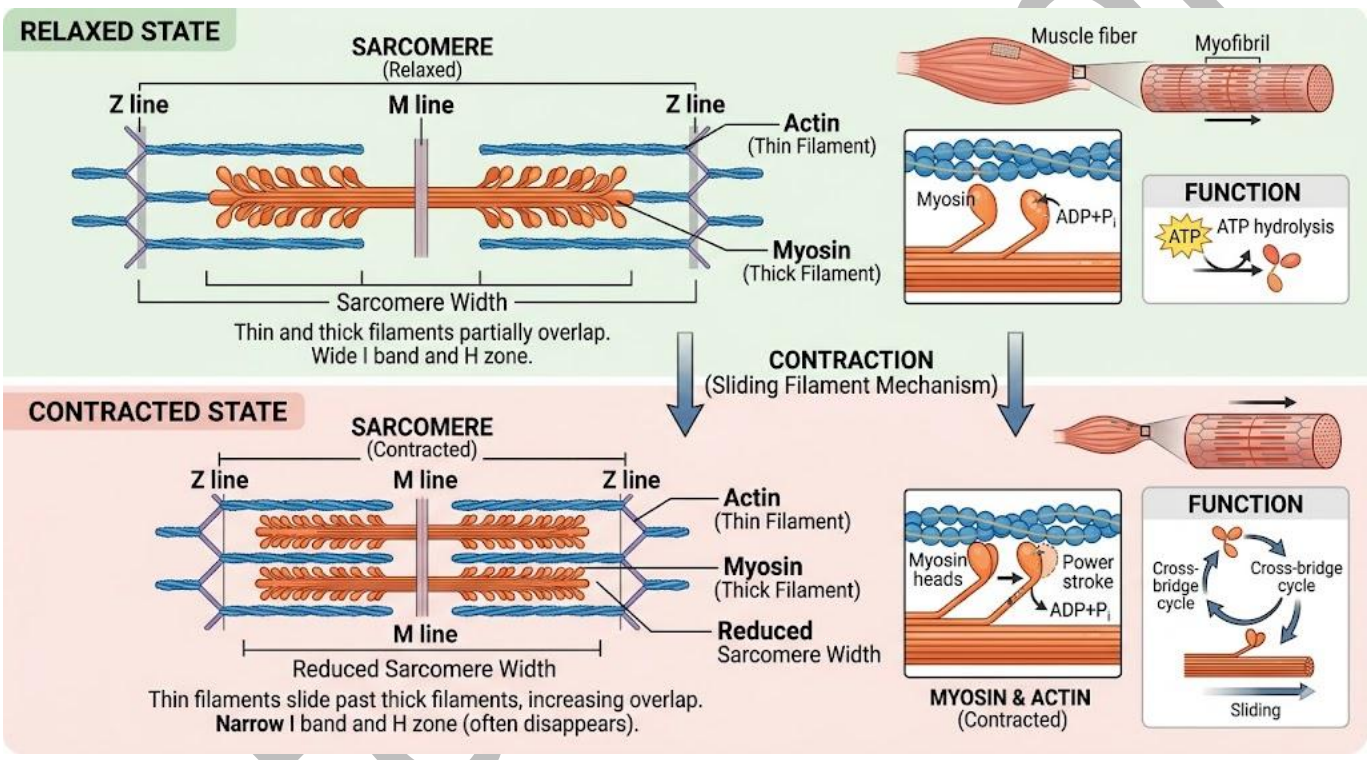

Figure 2.8: Diagram of the sliding filament mechanism of muscle contraction showing a sarcomere in relaxed and contracted states

Pilot questions 2.3

1. Distinguish between skeletal, cardiac, and smooth muscle tissue in terms of control, striations, and location.
2. Compare Type I and Type II skeletal muscle fibres in terms of speed, fatigue resistance, and metabolic pathway.
3. Name the major epaxial and hypaxial muscle groups and state the action of each.
4. Explain the sliding filament theory of muscle contraction.

5. Explain what happens to muscle glycogen after slaughter and why this is important for meat quality.

2.4 The Muscular System of Avian Species

2.4.1 Structural differences between avian and mammalian muscle

Avian skeletal muscle shares the same fundamental sliding filament mechanism as mammalian muscle but differs in several structural features. Birds have a fused clavicle (furcula or wishbone) and a keeled sternum (carina) that provides a greatly enlarged attachment surface for the pectoral flight muscles. The avian body is more compactly muscled, with most muscle mass concentrated proximally (close to the body centre of gravity) to improve balance and aerodynamic efficiency during flight.

Avian muscle fibres include a higher proportion of pale (Type II, fast-twitch, glycolytic) fibres in the breast muscles compared with mammalian trunk muscles, reflecting the explosive power required for wing beats in flying species. In domesticated broiler chickens selected for rapid breast muscle growth, virtually all breast muscle fibres are Type II, explaining why breast meat is pale and why broilers fatigue rapidly. Red (Type I, oxidative) fibres predominate in the leg muscles, which perform sustained locomotor work.

Fill in the blank: The keeled _____ of birds provides a greatly enlarged attachment surface for the pectoral muscles that power wing beats during flight.

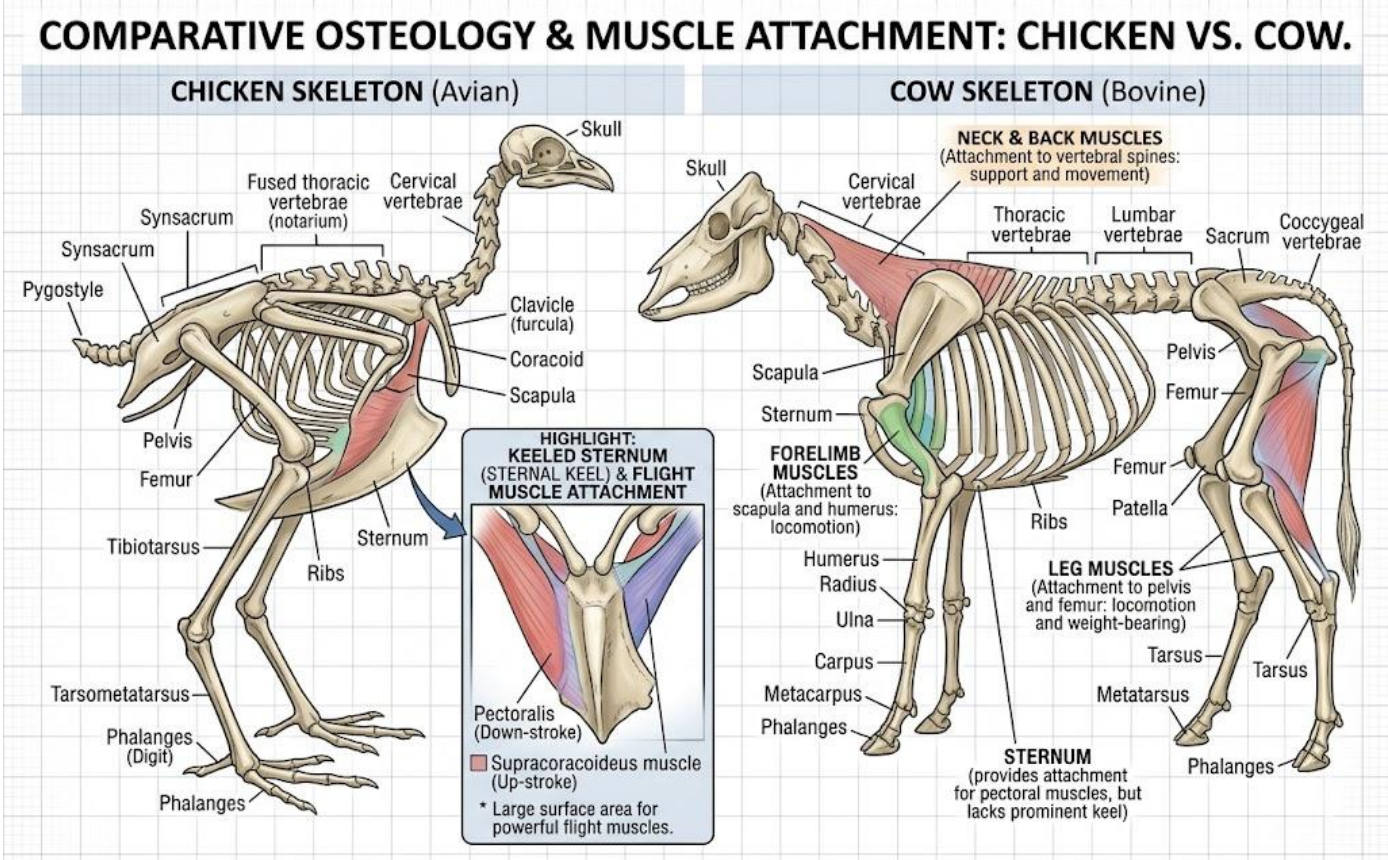

Figure 2.9: Diagram comparing the skeleton and major muscle attachments of a chicken and a cow

2.4.2 Major muscle groups of poultry

The most important muscle group in poultry is the pectoralis complex, which consists of the pectoralis major (the main downstroke muscle, the largest single muscle in the bird, forming the breast meat) and pectoralis minor (also called supracoracoideus, the upstroke muscle lying deep to the major). These muscles together account for 15 to 25 per cent of total body weight in well-muscled broilers and are the primary determinant of breast meat yield. The coracobrachialis, biceps brachii, and triceps control the wing.

In the hindlimb, the biceps femoris and iliotibialis muscles are the largest thigh muscles, forming the thigh meat (dark meat) of the carcass. The gastrocnemius (drumstick muscle) extends the hock and forms the leg meat. The iliofibularis, femorotibialis, and ambiens muscles contribute to thigh and lower leg mass. Unlike mammals, birds have no diaphragm muscle; breathing

movements are produced by the intercostal muscles and abdominal muscles acting on the rigid avian thoracoabdominal cavity.

Fill in the blank: The _____ major is the largest single muscle in the chicken, forms the breast meat, and powers the downstroke of the wing during flight.

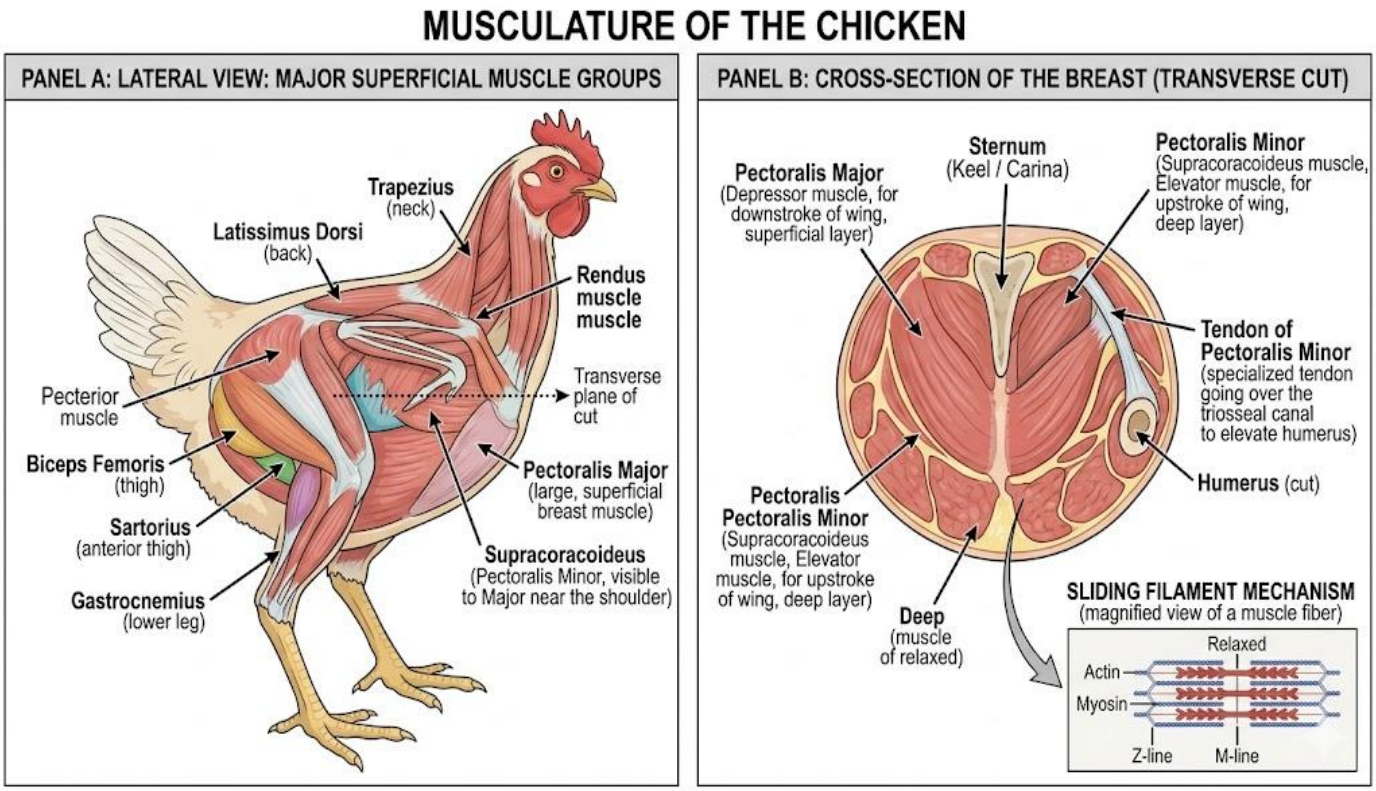

Figure 2.10: Diagram showing the major muscle groups of a chicken in lateral view and breast cross-section

2.4.3 Flight versus non-flight musculature and meat quality

The distinction between flight and non-flight muscles in poultry directly determines the colour and quality of poultry meat. White breast meat comes from the pectoralis muscles, which are composed predominantly of fast-twitch (Type II) glycolytic fibres with low myoglobin content. These fibres produce rapid, powerful wing strokes but fatigue quickly. The pale colour and fine texture of breast meat reflect its fibre composition. Dark leg meat comes from the thigh and drumstick muscles, which are composed predominantly of slow-twitch (Type I) oxidative fibres rich in myoglobin.

In commercial broiler production, genetic selection for large breast muscle has increased the proportion of Type II fibres to the point where affected birds may develop wooden breast (hardening and paleness of the pectoralis muscle due to fibre necrosis and fibrosis), white striping (white fat streaks along muscle fibres), and spaghetti meat (fragmentation of muscle fibres). These myopathies reduce meat quality and consumer acceptance. Understanding the fibre-type basis of these conditions guides breeding and management decisions to reduce their prevalence.

Fill in the blank: White breast meat in poultry is pale because the pectoralis muscle consists predominantly of fast-twitch Type II fibres with low _____ content, while dark leg meat is rich in myoglobin from Type I fibres.

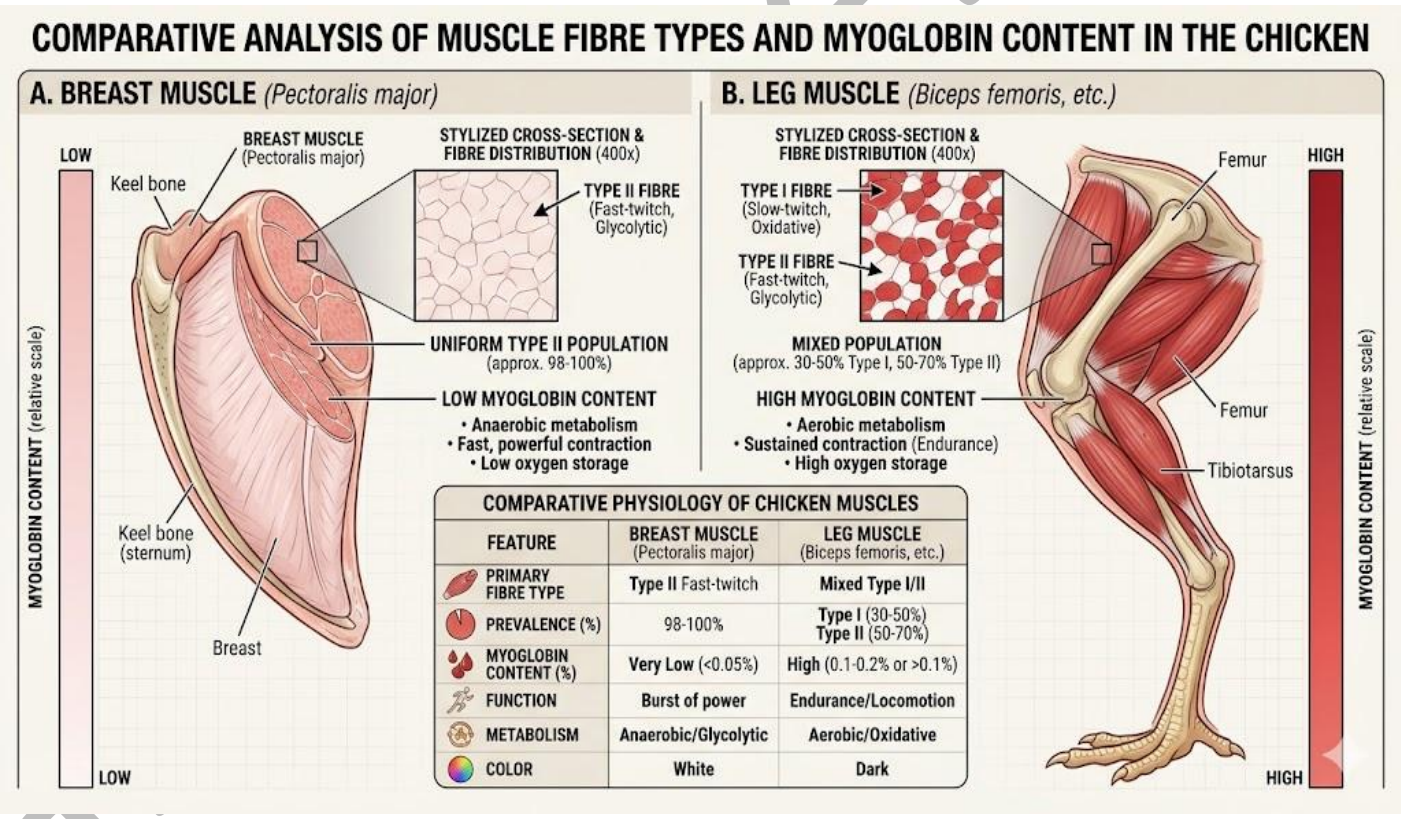

Figure 2.11: Diagram comparing Type I (red) and Type II (white) fibre distribution in breast and leg muscles of a chicken

Pilot questions 2.4

1. State two structural differences between the avian and mammalian skeleton relevant to muscle attachment.
2. Name the two components of the pectoralis complex and state the action of each.
3. Explain why broiler breast meat is pale while leg meat is dark.
4. Name two avian muscle myopathies associated with selection for large breast muscle and describe each briefly.
5. Explain why birds have no diaphragm and describe how they produce breathing movements.

Series Summary

This Series described the skeletal and muscular systems of farm animals. We began with the skeleton, covering its five functions, the distinction between axial and appendicular divisions, the structure of long bones, the five bone shape classes, and the major bones of cattle and poultry. We then examined joints, classifying them into fibrous, cartilaginous, and synovial types, describing the five components of a synovial joint, naming the major joints and their movements, and noting the key joint conditions affecting farm animal health.

We then covered the mammalian muscular system, comparing the three muscle tissue types, distinguishing Type I and Type II fibres, identifying the major epaxial, hypaxial, and limb muscle groups, and explaining the sliding filament mechanism of contraction and the post-mortem conversion of muscle to meat. Finally, we examined avian musculature, describing the keeled sternum, the pectoralis complex, the hindlimb muscles, and the fibre-type basis of white breast meat versus dark leg meat, including the broiler myopathies caused by extreme selection for breast muscle yield. By completing this Series, you should be able to achieve all eight Series Learning Outcomes (SLO 2.1 to SLO 2.8).

Glossary of Terms

- **Actin:** the thin contractile protein filament that interacts with myosin during muscle contraction in the sliding filament mechanism.
- **Appendicular skeleton:** the limbs and their girdles (pectoral and pelvic), as distinguished from the axial skeleton.
- **Arthritis:** inflammation of a joint causing pain, swelling, heat, and reduced range of movement.
- **Axial skeleton:** the skull, vertebral column, ribs, and sternum forming the central axis of the body.
- **Cancellous bone:** porous spongy bone found in the epiphyses of long bones and in flat bones; contains red marrow for haematopoiesis.

- **Cardiac muscle:** involuntary striated muscle forming the myocardium (heart wall); self-stimulating through its own conduction system.
- **Compact bone:** dense bone forming the cortex (outer wall) of long bones; provides strength and rigidity.
- **Creatine phosphate:** a high-energy compound in muscle cells that rapidly donates phosphate to ADP to regenerate ATP at the onset of contraction.
- **Diaphysis:** the shaft of a long bone, consisting of a compact bone cylinder surrounding the medullary cavity.
- **Epiphysis:** the end of a long bone consisting of cancellous bone covered by articular cartilage; separated from the diaphysis by the epiphyseal growth plate in growing animals.
- **Fibrous joint:** an immovable joint in which bones are connected by fibrous connective tissue; examples include skull sutures.
- **Haematopoiesis:** the production of blood cells (red and white blood cells and platelets) in the red bone marrow of cancellous bone.
- **Laminitis:** inflammation of the sensitive laminae of the hoof causing severe lameness; associated with grain overload and metabolic disease in cattle and horses.
- **Ligament:** a fibrous connective tissue band connecting bone to bone and stabilising joints.
- **Longissimus dorsi:** the largest epaxial muscle, running along the back parallel to the vertebral column; the primary source of loin meat in cattle and pigs.
- **Myoglobin:** an oxygen-binding pigment in muscle cells that stores oxygen and gives red muscle its colour; abundant in Type I slow-twitch fibres.
- **Myosin:** the thick contractile protein filament whose heads interact with actin to generate the power stroke of muscle contraction.
- **Osteochondrosis dissecans (OCD):** a developmental joint disease in which articular cartilage fails to ossify correctly, producing cartilage flaps and joint effusion; common in rapidly growing pigs and horses.
- **Pectoralis major:** the largest single muscle in birds, forming the breast meat and powering the downstroke of the wing; composed predominantly of fast-twitch Type II fibres.

- **Periosteum:** the fibrous membrane covering the outer surface of bone (except articular surfaces); anchors tendons and supports bone repair.
- **Rigor mortis:** post-mortem stiffening of muscle caused by depletion of ATP, which prevents detachment of myosin from actin; resolves as enzymes degrade sarcomere proteins during conditioning.
- **Sarcomere:** the basic contractile unit of skeletal muscle, bounded by Z lines and containing interdigitating thick (myosin) and thin (actin) filaments.
- **Septic arthritis:** bacterial infection of a joint causing inflammation and joint ill; common in newborn calves and lambs infected through the navel.
- **Skeletal muscle:** voluntary striated muscle attached to bone via tendons; responsible for locomotion and posture.
- **Sliding filament theory:** the mechanism explaining muscle contraction in which myosin heads bind to actin and pull thin filaments towards the centre of the sarcomere, shortening it.
- **Smooth muscle:** involuntary non-striated muscle in the walls of hollow organs; controls diameter and movement of those organs.
- **Synovial fluid:** viscous fluid secreted by the synovial membrane lining joint capsules; lubricates articular surfaces and nourishes articular cartilage.
- **Synovial joint:** a freely movable joint with articular cartilage, a joint capsule lined by synovial membrane, and synovial fluid; the most common joint type involved in locomotion.
- **Tendon:** a dense fibrous connective tissue cord connecting muscle to bone.
- **Type I fibre:** slow-twitch, oxidative, fatigue-resistant skeletal muscle fibre rich in myoglobin; supports sustained activity.
- **Type II fibre:** fast-twitch, glycolytic skeletal muscle fibre with low myoglobin; produces powerful rapid contractions but fatigues quickly.
- **Wooden breast:** a broiler myopathy causing hardening and paleness of the pectoralis muscle due to fibre necrosis and fibrosis; associated with extreme selection for breast muscle yield.

Concept Check Questions [Series 2]

Objective Questions

6. The skeleton is divided into the _____ skeleton (skull, vertebral column, ribs, sternum) and the appendicular skeleton. (Linked to SLO 2.1)
7. The shaft of a long bone is called the _____ and consists of compact bone surrounding a medullary cavity. (Linked to SLO 2.1)
8. Synovial joints are lubricated by _____ fluid secreted by the synovial membrane. (Linked to SLO 2.3)
9. Type I skeletal muscle fibres are resistant to _____ and rely on aerobic metabolism. (Linked to SLO 2.5)
10. The pectoralis major powers the wing _____ stroke and is the largest single muscle in the chicken, forming the breast meat. (Linked to SLO 2.8)

Short-Answer Questions

11. State the five functions of the skeleton. (Linked to SLO 2.1)
12. Describe the five structural components of a synovial joint. (Linked to SLO 2.3)
13. Compare Type I and Type II skeletal muscle fibres. (Linked to SLO 2.5)
14. Explain the sliding filament theory of muscle contraction. (Linked to SLO 2.7)
15. Explain why broiler breast meat is pale and leg meat is dark. (Linked to SLO 2.8)

Long-Answer Questions

14. Describe the skeletal system of farm animals, explaining bone structure and types, identifying the major bones of the axial and appendicular skeleton, and comparing skeletal features of cattle and poultry. (Linked to SLOs 2.1, 2.2)
15. Discuss the classification, structure, and major examples of joints in farm animals, and describe the most important joint conditions affecting production and welfare. (Linked to SLOs 2.3, 2.4)

16. Evaluate the muscular systems of mammals and avian species, comparing muscle fibre types, major muscle groups, the mechanism of contraction, and the implications of muscle fibre composition for meat quality in both cattle and poultry. (Linked to SLOs 2.5, 2.6, 2.7, 2.8)

Answers to Concept Check Questions [Series 2]

Objective Questions

1. Axial.
2. Diaphysis.
3. Synovial.
4. Fatigue.
5. Down.

Short-Answer Questions

1. Support (structural framework); protection (of brain, spinal cord, and thoracic organs); movement (providing levers for muscle action); mineral storage (calcium and phosphorus); blood cell production (haematopoiesis in red bone marrow).
2. Articular cartilage (covers bone ends, reduces friction); joint capsule fibrous layer (encloses the joint); synovial membrane (inner lining, secretes synovial fluid); synovial fluid (lubricates and nourishes articular cartilage); ligaments (fibrous bands connecting bone to bone, stabilising the joint).
3. Type I (slow-twitch): contract slowly, highly fatigue-resistant, rely on aerobic oxidative metabolism, rich in myoglobin (red colour), support sustained activity such as posture. Type II (fast-twitch): contract rapidly, fatigue quickly, rely on anaerobic glycolysis, low myoglobin (pale), produce powerful short-duration contractions for locomotion and escape.
4. The sarcomere is the contractile unit, bounded by Z lines and containing interdigitating thick myosin filaments and thin actin filaments. A nerve impulse triggers calcium release from the sarcoplasmic reticulum; calcium allows myosin heads to bind to actin and perform a power stroke that pulls thin filaments towards the sarcomere centre, shortening the sarcomere and the whole muscle. ATP is required to detach the myosin head and reset it for the next stroke.

5. Breast meat is pale because the pectoralis major consists predominantly of fast-twitch Type II glycolytic fibres with low myoglobin content, reflecting the explosive short-duration power needed for wing beats. Leg meat is dark because the thigh and drumstick muscles consist predominantly of slow-twitch Type I oxidative fibres rich in myoglobin, reflecting the sustained locomotor activity of the legs.

Long-Answer Questions

1. The skeleton performs five functions: support, protection, movement, mineral storage, and haematopoiesis. The axial skeleton comprises the skull, vertebral column, ribs, and sternum; the appendicular skeleton comprises the limbs and girdles. Long bone structure: diaphysis of compact bone, epiphyses of cancellous bone, periosteum, endosteum, medullary cavity. Bone types: long (humerus, lever), short (carpals, concussion absorption), flat (scapula, protection and muscle attachment), irregular (vertebrae), sesamoid (patella). Bovine forelimb: scapula, humerus, radius-ulna, carpus, metacarpus, two main digits. Bovine hindlimb: pelvis, femur, tibia, tarsus, metatarsus, digits. Poultry differences: fused synsacrum and pygostyle, keeled sternum, furcula, reduced and fused wing bones.
2. Joints: fibrous (immovable, skull sutures), cartilaginous (slight movement, intervertebral discs, pubic symphysis), synovial (freely movable, five components: articular cartilage, fibrous capsule, synovial membrane, synovial fluid, ligaments). Major joints: shoulder (ball-and-socket), elbow (hinge), carpus (compound hinge), fetlock (hinge, weight-bearing), stifle (complex, cruciate ligaments and menisci), hip (ball-and-socket), hock (hinge). Joint conditions: septic arthritis (bacterial, navel entry, newborn calves and lambs, stifle-hock-fetlock); OCD (cartilage ossification failure, growing pigs and horses); foot rot (Fusobacterium necrophorum, interdigital, wet conditions); laminitis (sensitive laminae inflammation, grain overload, cattle-horses-goats).
3. Muscle types: skeletal (voluntary, striated, tendons to bone), cardiac (involuntary, striated, self-stimulating), smooth (involuntary, non-striated, hollow organs). Fibre types: Type I (slow, aerobic, fatigue-resistant, red); Type II (fast, glycolytic, fatigues quickly, pale). Major mammalian muscles: longissimus dorsi (epaxial, back extension, loin meat), gluteus (hip extension), triceps brachii (elbow extension), quadriceps (stifle extension), biceps femoris (stifle flexion, hip extension). Sliding filament: sarcomere shortens as myosin heads pull actin; calcium triggers, ATP detaches heads. Post-mortem: glycogen to lactic acid, pH falls, rigor mortis, meat conditioning. Avian: keeled sternum, pectoralis major (breast, downstroke, Type II, pale), pectoralis minor (upstroke), hindlimb muscles (Type I, dark). Myopathies

from selection for breast yield: wooden breast (necrosis and fibrosis), white striping (fat streaks).

Answers to Pilot Questions [Series 2]

Part 2.1: The Skeletal System

1. Support (structural framework); protection (brain, spinal cord, heart, lungs); movement (lever system for muscles); mineral storage (calcium and phosphorus); haematopoiesis (red and white blood cell production in red bone marrow).
2. Axial skeleton: central axis of the body; examples: skull (protects brain) and vertebral column (protects spinal cord). Appendicular skeleton: limbs and their girdles; examples: humerus (forelimb) and femur (hindlimb).
3. Five components: (1) diaphysis (compact bone shaft); (2) epiphyses (cancellous bone ends, covered by articular cartilage); (3) periosteum (fibrous outer membrane anchoring tendons); (4) endosteum (lining of the medullary cavity); (5) medullary cavity (containing yellow marrow in adults, red marrow in growing animals).
4. Long (humerus, femur: lever for locomotion); short (carpals, tarsals: absorb concussion); flat (scapula, ilium: protect organs or provide large muscle attachment); irregular (vertebrae: mixed structural and protective functions); sesamoid (patella, navicular: reduce tendon friction at joints).
5. Scapula, humerus, radius and ulna, carpus (knee), metacarpus (cannon bone), digits III and IV with dewclaws (digits II and V).

Part 2.2: Joints of Farm Animals

1. Fibrous joints (synarthroses): immovable; example: skull sutures. Cartilaginous joints (amphiarthroses): slightly movable; example: intervertebral discs. Synovial joints (diarthroses): freely movable; example: stifle joint.
2. Articular cartilage (covering bone ends); fibrous joint capsule (enclosing the joint); synovial membrane (inner lining of the capsule); synovial fluid (lubricating and nourishing articular surfaces); ligaments (reinforcing the capsule and connecting bone to bone).
3. Shoulder (scapulohumeral): ball-and-socket, allows flexion, extension, and some rotation. Elbow (humeroulnar): hinge, allows flexion and extension. Stifle (femorotibial and

femoropatellar): complex hinge with cruciate ligaments and menisci, allows flexion and extension with some rotation.

4. Septic arthritis is bacterial infection of a joint causing inflammation, pain, swelling, and impaired movement. In newborn calves and lambs the most common route is entry of bacteria (commonly Escherichia coli, Streptococcus, or Staphylococcus) through the umbilical remnant (navel) in the first days of life, particularly when passive transfer of colostral immunoglobulins has been inadequate.
5. Laminitis is inflammation of the sensitive laminae of the hoof, causing severe lameness and pain. Two predisposing factors: grain overload (sudden access to large quantities of starch causes ruminal acidosis, releasing endotoxins that damage the lamellar vasculature); metabolic disease (periparturient metabolic disturbances in high-yielding dairy cows, particularly subclinical acidosis, increase risk).

Part 2.3: The Muscular System of Mammals

1. Skeletal muscle: voluntary control, striated, attached to bone via tendons, responsible for locomotion. Cardiac muscle: involuntary, striated, self-stimulating via own conduction system, forms the heart wall. Smooth muscle: involuntary, non-striated, in walls of hollow organs (intestines, blood vessels, uterus), controls their diameter and movement.
2. Type I (slow-twitch): contract slowly, highly fatigue-resistant, aerobic oxidative metabolism, rich in myoglobin (red colour), high mitochondrial density, support sustained posture and locomotion. Type II (fast-twitch): contract rapidly, fatigue quickly, anaerobic glycolytic metabolism, low myoglobin (pale colour), fewer mitochondria, produce powerful short bursts of force for locomotion and escape.
3. Epaxial muscles (dorsal to vertebral column): longissimus dorsi, semispinalis, multifidus; action: extend and stabilise the back. Hypaxial muscles (ventral to vertebral column): psoas major, psoas minor, iliacus; action: flex the lumbar spine and protract the pelvic limb.
4. The sarcomere is the contractile unit bounded by Z lines. Thick myosin filaments and thin actin filaments interdigitate within it. A motor nerve impulse releases acetylcholine at the neuromuscular junction, generating an action potential that travels along the muscle fibre and into T-tubules, triggering calcium release from the sarcoplasmic reticulum. Calcium binds to troponin, displacing tropomyosin and exposing myosin-binding sites on actin. Myosin heads bind to actin, perform a power stroke (pulling actin towards the M line), then detach using ATP and reset for the next stroke, repeating until the nerve impulse ceases.

5. After slaughter, circulation stops and oxygen supply ceases. Muscle cells continue anaerobic glycolysis, converting glycogen to lactic acid. Lactic acid accumulates, lowering muscle pH from approximately 7.2 to 5.5 (ultimate pH). This pH drop denatures some proteins and affects water-holding capacity of meat. ATP depletion prevents myosin from detaching from actin, causing rigor mortis (muscle stiffening). As conditioning (ageing) proceeds, proteolytic enzymes degrade sarcomere proteins, resolving rigor and tenderising the meat.

Part 2.4: The Muscular System of Avian Species

1. Two structural differences: (1) birds have a keeled sternum (carina) providing a greatly enlarged ventral surface for attachment of the massive pectoral muscles, while mammals have a flat sternum with limited pectoral attachment area; (2) birds have a fused clavicle (furcula or wishbone) that acts as a spring storing and returning energy during wing beats, while mammals have separate clavicles or lack them entirely.
2. Pectoralis major: the larger component, forms the breast meat, powers the downstroke of the wing; composed of Type II fast-twitch fibres. Pectoralis minor (supracoracoideus): lies deep to the major, powers the upstroke of the wing; has a unique tendon that passes through the triosseal canal to attach on the dorsal humerus, allowing it to act from below.
3. Breast meat is pale because the pectoralis major consists almost entirely of fast-twitch Type II glycolytic fibres with very low myoglobin content; myoglobin is the pigment that makes muscle red, and its absence results in pale meat. Leg meat is dark because the thigh (biceps femoris, iliotibialis) and drumstick (gastrocnemius) muscles are composed predominantly of slow-twitch Type I oxidative fibres that are rich in myoglobin, reflecting their role in sustained weight-bearing locomotion.
4. Wooden breast: hardening and paleness of the pectoralis major caused by fibre necrosis followed by replacement with fibrotic connective tissue and fat; the affected breast feels hard to the touch and has reduced water-holding capacity, reducing meat quality. White striping: white fat streaks running parallel to muscle fibres in the pectoralis major, caused by fat infiltration between muscle fibre bundles; reduces protein content and increases fat content of the breast fillet.
5. Birds have no muscular diaphragm separating thoracic and abdominal compartments as mammals do; the avian coelom is not divided in the same way. Breathing is produced by the coordinated contraction and relaxation of the intercostal muscles and the abdominal muscles, which change the volume of the thoracoabdominal cavity and drive air through the unique avian parabronchial lung and air sac system.

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Figures, Plates, Tables, and Boxes

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Course code: AGE 204

Course title: Anatomy and Physiology of Farm Animals

Course credit load: 2 Units

Series 3: Digestive Physiology of Mammals and Avian Species

- **Part 3.1: The Mammalian Digestive System**
  - Sub Part 3.1.1: Overview and components of the digestive tract
  - Sub Part 3.1.2: The mouth, oesophagus, and stomach
  - Sub Part 3.1.3: The small and large intestines
- **Part 3.2: Ruminant Digestive Physiology**
  - Sub Part 3.2.1: The four-chambered stomach
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  - Sub Part 3.2.3: Rumination, eructation, and fermentation products
- **Part 3.3: Monogastric Digestive Physiology**
  - Sub Part 3.3.1: Digestion in the pig
  - Sub Part 3.3.2: Digestive enzymes and nutrient absorption
  - Sub Part 3.3.3: The large intestine and hindgut fermentation
- **Part 3.4: Avian Digestive Physiology**
  - Sub Part 3.4.1: Unique features of the avian digestive tract
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Introduction

Digestion is the process by which feed is broken down into molecules small enough to be absorbed and used by the body. The anatomy of the digestive tract determines what feeds an animal can utilise and how efficiently it can extract energy and nutrients from them. Ruminants, monogastrics, and birds have profoundly different digestive systems that reflect millions of years of adaptation to different diets and feeding strategies.

The aim of this Series is to describe the structure and function of the mammalian digestive tract, explain the unique physiology of ruminant digestion, cover monogastric digestion in the pig, and describe the distinctive features of the avian digestive system. We shall begin with the general mammalian tract, move to ruminant and monogastric comparisons, and conclude with avian digestion and its agricultural significance.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 3.1** describe the components and functions of the mammalian digestive tract (Linked to Part 3.1),
- **SLO 3.2** describe the structure and function of the mouth, oesophagus, and stomach in mammals (Linked to Part 3.1),
- **SLO 3.3** explain the roles of the small and large intestines in digestion and absorption (Linked to Part 3.1),
- **SLO 3.4** describe the four chambers of the ruminant stomach and their functions (Linked to Part 3.2),
- **SLO 3.5** explain rumen fermentation, the rumen microbiome, and the products of fermentation (Linked to Part 3.2),
- **SLO 3.6** describe rumination and eructation and explain their importance to ruminant health (Linked to Part 3.2),
- **SLO 3.7** describe digestion and nutrient absorption in the pig as a model monogastric (Linked to Part 3.3),

- **SLO 3.8** describe the unique features of the avian digestive tract including the crop, proventriculus, gizzard, and cloaca (Linked to Part 3.4), and
- **SLO 3.9** compare the efficiency and limitations of ruminant, monogastric, and avian digestive systems for farm animal production (Linked to Parts 3.2, 3.3, 3.4).

3.1 The Mammalian Digestive System

3.1.1 Overview and components of the digestive tract

The mammalian digestive system consists of the alimentary canal (a continuous tube from mouth to anus) and the accessory digestive organs. The alimentary canal comprises the mouth, pharynx, oesophagus, stomach, small intestine, large intestine, and rectum. The accessory organs (salivary glands, liver, gallbladder, and pancreas) produce secretions that enter the canal to assist digestion but are not part of the tube itself.

The wall of the digestive tract has four layers: the mucosa (inner lining of epithelial cells involved in secretion and absorption), the submucosa (connective tissue with blood vessels and nerves), the muscularis (smooth muscle layers producing peristalsis), and the serosa (outer peritoneal covering). Peristalsis is the coordinated wave of smooth muscle contraction that propels ingesta along the tract. The entire tract is controlled by the enteric nervous system, which operates largely independently of the brain.

Fill in the blank: The wall of the digestive tract has four layers: the mucosa, submucosa, muscularis, and _____, which is the outer peritoneal covering.

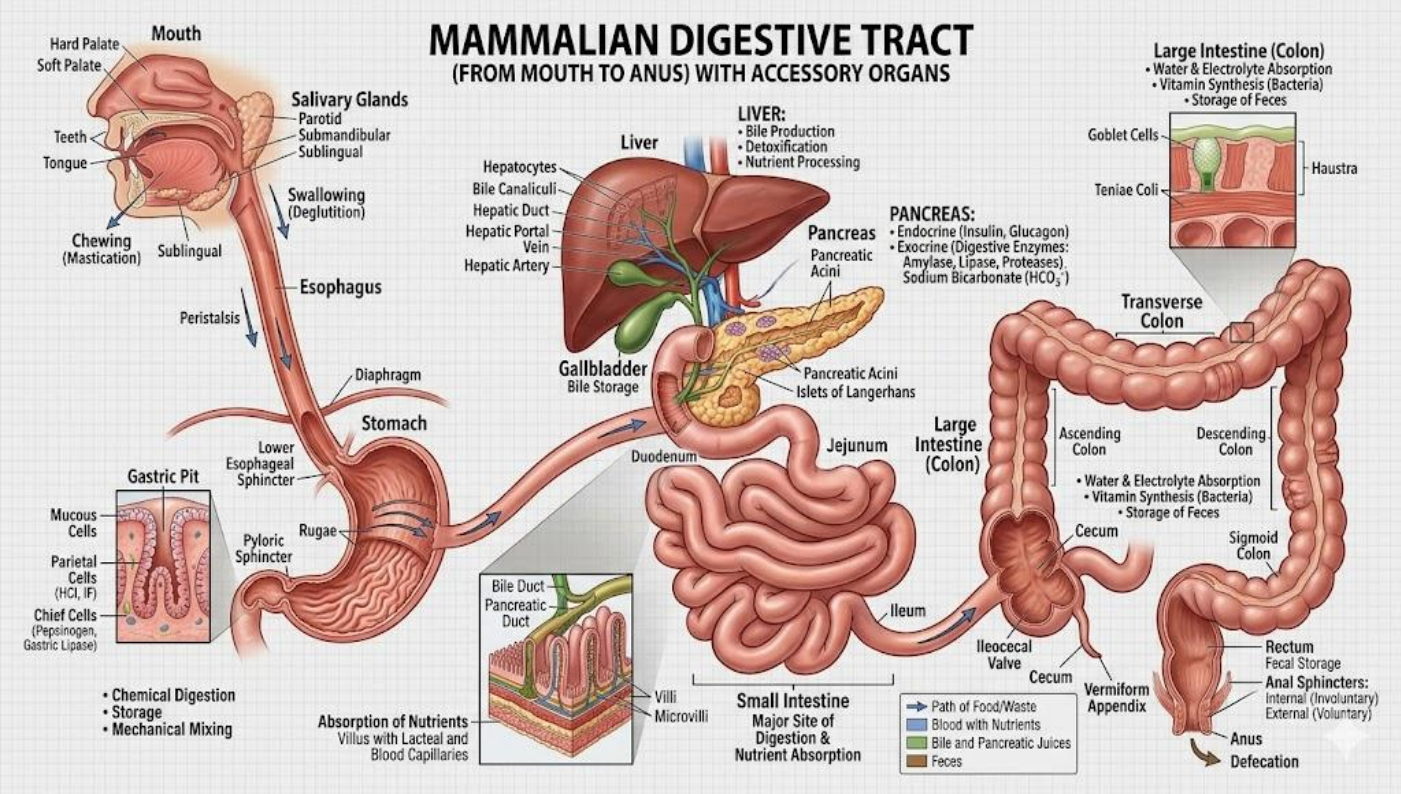


Figure 3.1: Diagram of the mammalian digestive tract showing all components from mouth to anus

3.1.2 The mouth, oesophagus, and stomach

Digestion begins in the mouth, where teeth mechanically break down feed and salivary amylase begins starch hydrolysis. Saliva also lubricates the bolus for swallowing. The pharynx connects the mouth to the oesophagus; swallowing is a reflex that closes the larynx (via the epiglottis) to prevent food entering the trachea. The oesophagus is a muscular tube that moves the bolus to the stomach by peristalsis; it has no digestive function.

The stomach is a muscular sac that stores ingesta, continues mechanical breakdown by churning, and secretes gastric juice (hydrochloric acid and pepsin) for protein digestion. Gastric acid (pH 1.5 to 3.5) denatures proteins and kills most ingested bacteria. The stomach empties into the duodenum through the pyloric sphincter, which regulates the rate of gastric emptying. In ruminants, the stomach is replaced by the four-chambered forestomach and abomasum, described in Part 3.2.

Fill in the blank: Gastric juice contains hydrochloric acid (pH 1.5 to 3.5) and the enzyme _____, which begins the digestion of proteins in the stomach.

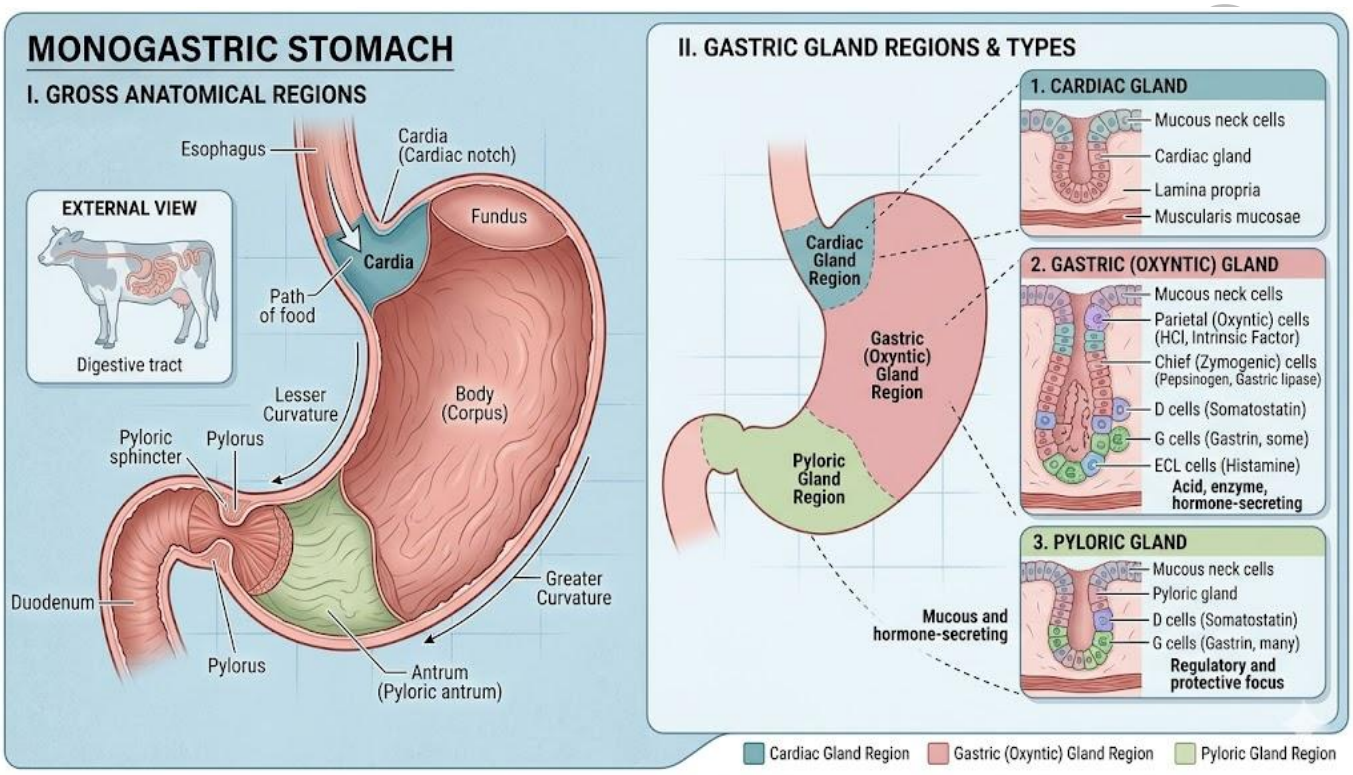


Figure 3.2: Diagram of the stomach of a monogastric animal showing its regions and the pyloric sphincter

3.1.3 The small and large intestines

The small intestine is the primary site of nutrient digestion and absorption. It is divided into three segments: the duodenum (receives bile from the liver and pancreatic juice from the pancreas), the jejunum (the main site of absorption), and the ileum (absorbs bile salts and vitamin B12). The mucosal surface is enormously amplified by circular folds, villi (finger-like projections), and microvilli (brush border), increasing absorptive area by up to 600-fold over a plain tube.

The large intestine (caecum, colon, and rectum) absorbs water and electrolytes from the remaining ingesta, forming faeces. In some species (horse, rabbit) the caecum also harbours microbial fermentation of fibrous material, making it a functional hindgut fermentation chamber. The rectum stores faeces until defecation. The liver produces bile (for fat emulsification), and the

pancreas produces a bicarbonate-rich juice that neutralises stomach acid entering the duodenum along with lipase, amylase, and proteases.

Fill in the blank: The mucosal surface of the small intestine is amplified by circular folds, villi, and _____ (brush border), increasing absorptive surface area up to 600-fold.

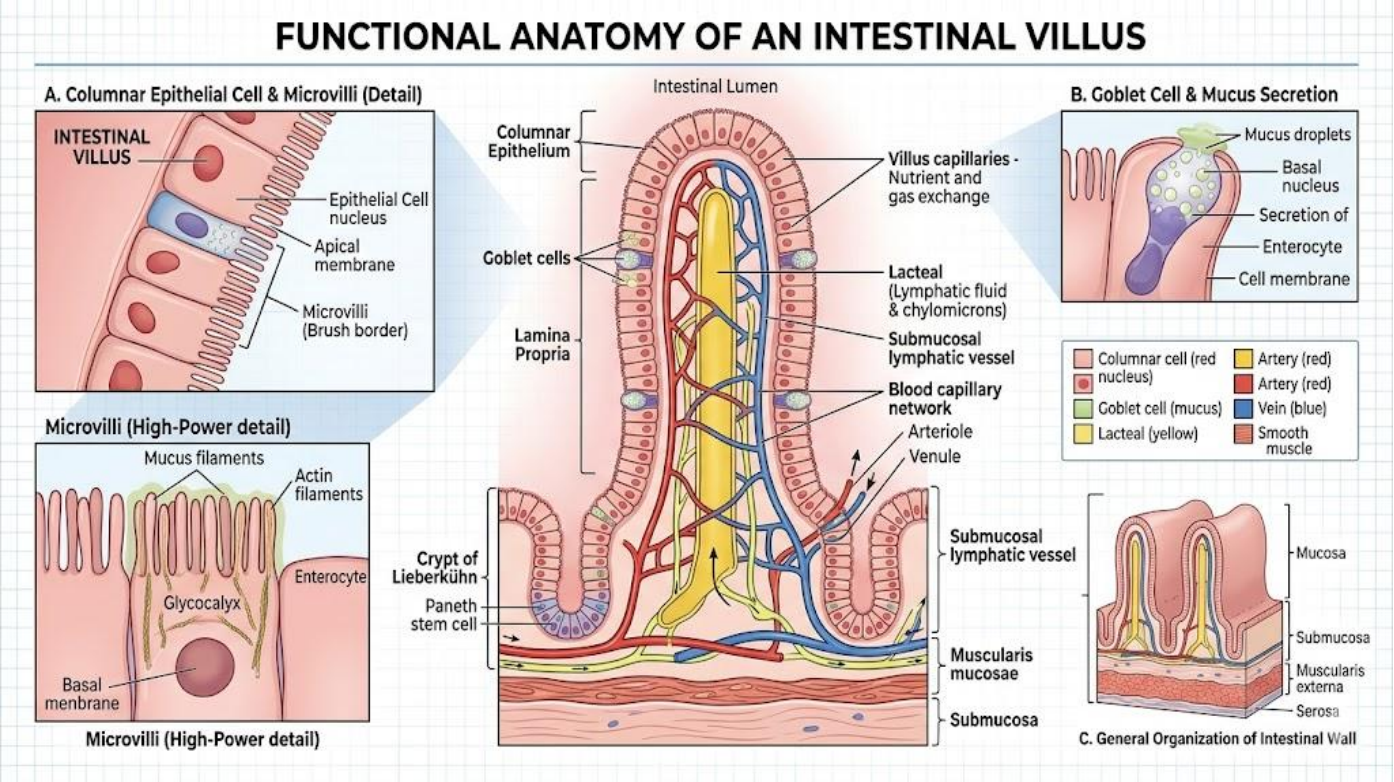


Figure 3.3: Diagram of a villus in the small intestine showing its structural components

Pilot questions 3.1

1. Name the five components of the alimentary canal in order from mouth to anus.
2. State the four layers of the digestive tract wall and the function of each.
3. Describe the role of gastric juice in stomach digestion.
4. Name the three segments of the small intestine and state the main function of each.
5. Explain how the mucosal surface of the small intestine is amplified for absorption.

3.2 Ruminant Digestive Physiology

3.2.1 The four-chambered stomach

Ruminants (cattle, sheep, goats, deer) have a complex stomach divided into four chambers: the rumen, reticulum, omasum, and abomasum. The rumen is the largest chamber, occupying most of the left side of the abdominal cavity in adult cattle (capacity 100 to 200 litres); it is a fermentation vat where microorganisms digest fibrous feeds. The reticulum lies cranioventral to the rumen, is lined with a honeycomb mucosa, and is the site where ingested metal objects accumulate (causing hardware disease).

The omasum is a spherical organ with lamellae (leaf-like folds) that grind and squeeze digesta, absorbing water and volatile fatty acids. The abomasum is the true glandular stomach equivalent to the monogastric stomach; it secretes hydrochloric acid and pepsin to digest the microbial protein and undegraded feed protein passing from the forestomach. In the newborn calf, the oesophageal groove reflex bypasses the rumen and reticulum, directing milk directly to the abomasum.

Fill in the blank: The _____ is the true glandular stomach of ruminants, equivalent to the monogastric stomach, and secretes hydrochloric acid and pepsin for protein digestion.

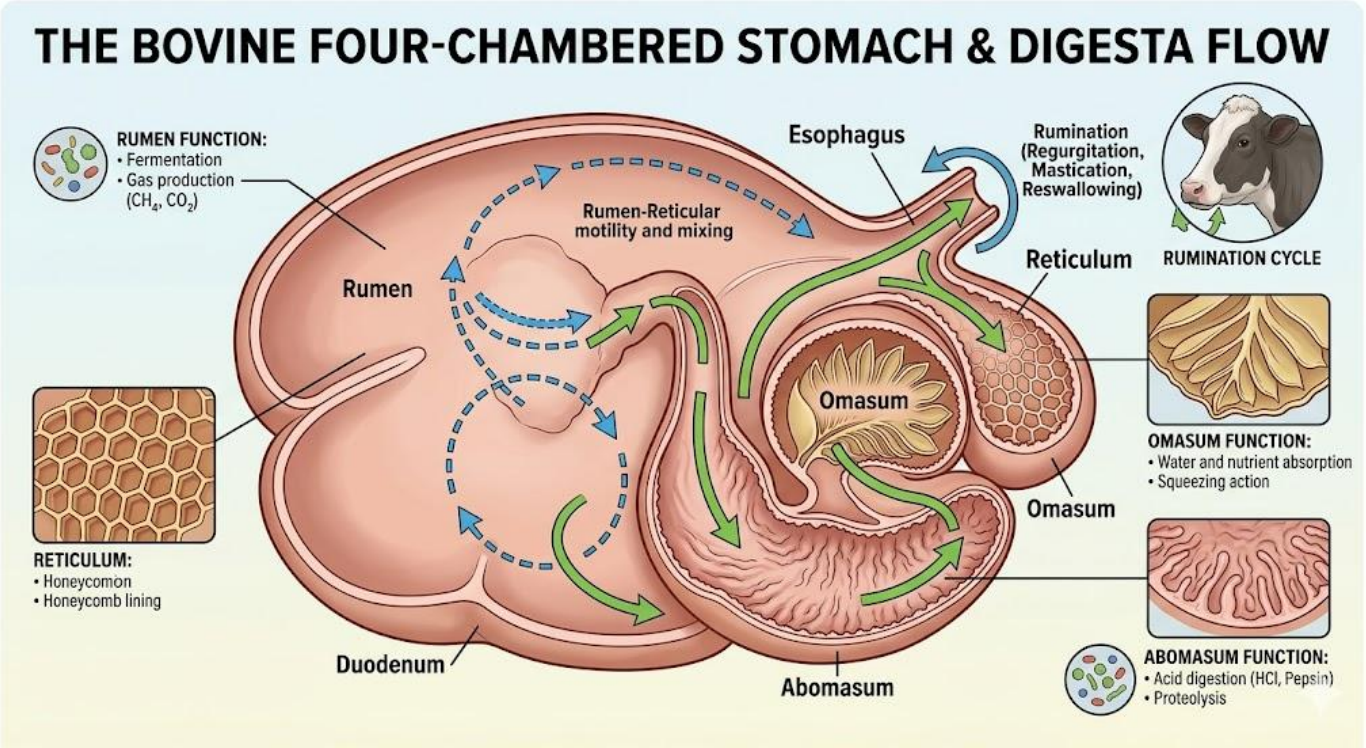


Figure 3.4: Diagram of the four-chambered ruminant stomach showing chambers and their relative positions

3.2.2 Rumen fermentation and microbiology

The rumen contains a complex and diverse microbial community of bacteria, protozoa, and fungi that collectively ferment carbohydrates (cellulose, hemicellulose, starch, and sugars) that the animal itself cannot digest. Cellulolytic bacteria (Fibrobacter succinogenes, Ruminococcus spp.) break down plant cell walls. Amylolytic bacteria digest starch. Proteolytic bacteria degrade dietary protein, though excessive degradation is wasteful. The rumen environment is maintained at 38 to 42°C, pH 6.0 to 7.0, and near-anaerobic conditions, which are optimal for microbial activity.

Rumen microorganisms provide two major nutritional benefits to the host: they ferment structural carbohydrates (cellulose) that the animal cannot digest alone, and they synthesise microbial protein of high biological value from ammonia and dietary nitrogen. The microbial cells passing from the rumen to the abomasum and small intestine provide 50 to 80 per cent of the total amino acid supply of ruminants. This capacity to convert non-protein nitrogen (urea,

ammonium salts) into high-quality microbial protein is the basis of urea supplementation in ruminant feeds.

Fill in the blank: The rumen provides two key nutritional benefits: it ferments _____ (plant cell walls) that the animal cannot digest alone, and it synthesises microbial protein from dietary nitrogen.

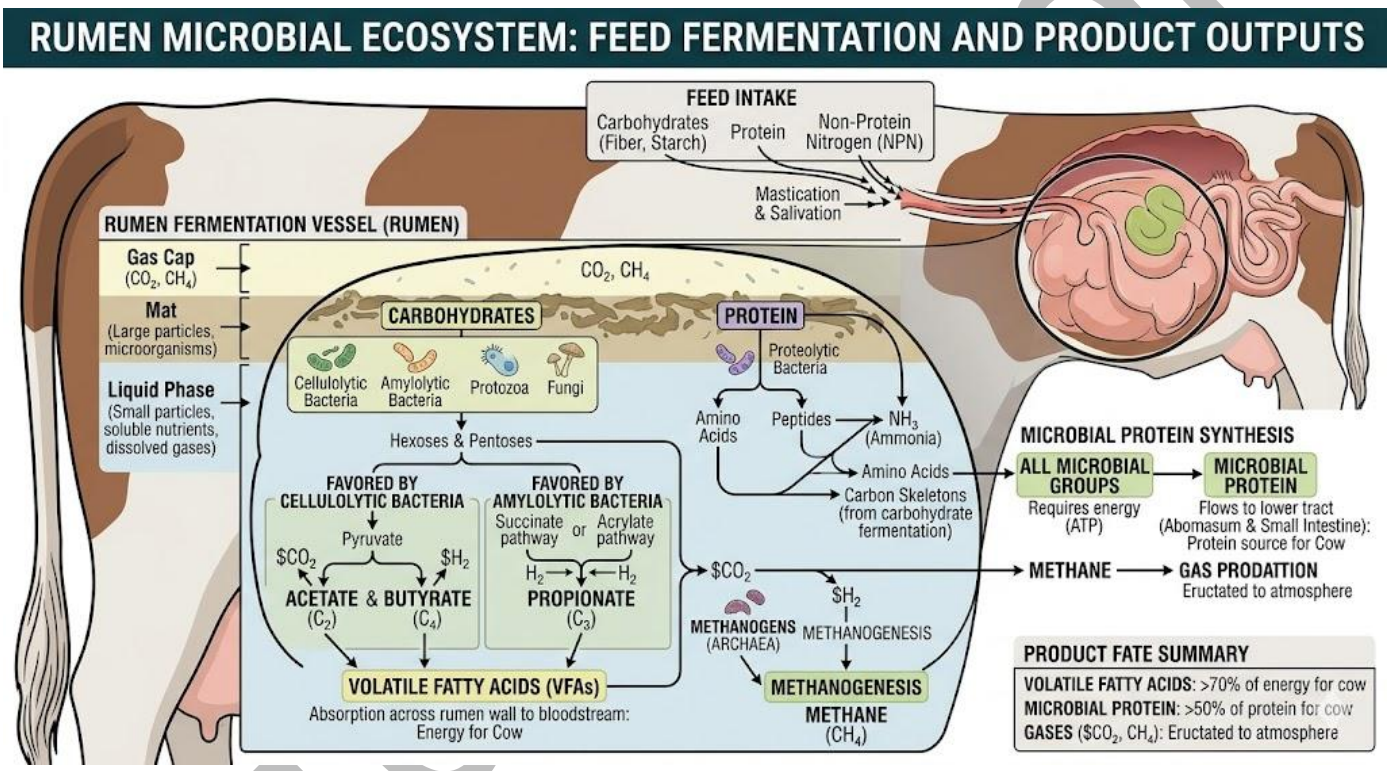


Figure 3.5: Diagram showing the rumen microbial ecosystem and its fermentation products

3.2.3 Rumination, eructation, and fermentation products

Rumination (cud chewing) is the process by which coarse rumen contents are regurgitated to the mouth, re-chewed to reduce particle size, mixed with saliva, and re-swallowed. It is essential for efficient rumen function because particle size reduction increases the surface area available to microbial attack. Adult cattle spend 6 to 10 hours per day ruminating. Cessation of rumination is an early sign of rumen dysfunction or systemic illness and is a key clinical observation in cattle health assessment.

The primary fermentation products are volatile fatty acids (VFAs): acetate (the most abundant, precursor for fat synthesis and energy), propionate (precursor for glucose synthesis via gluconeogenesis), and butyrate (energy source and stimulates rumen papillae development). Fermentation also produces large volumes of CO2 and methane gas. Eructation is the belching of these gases from the rumen via the oesophagus; if eructation is blocked (for example, when frothy foam traps gas at the rumen surface), bloat develops rapidly and can be fatal if not relieved promptly.

Fill in the blank: The three main volatile fatty acids produced by rumen fermentation are acetate, _____, and butyrate; propionate is the main VFA precursor for glucose synthesis in the liver.

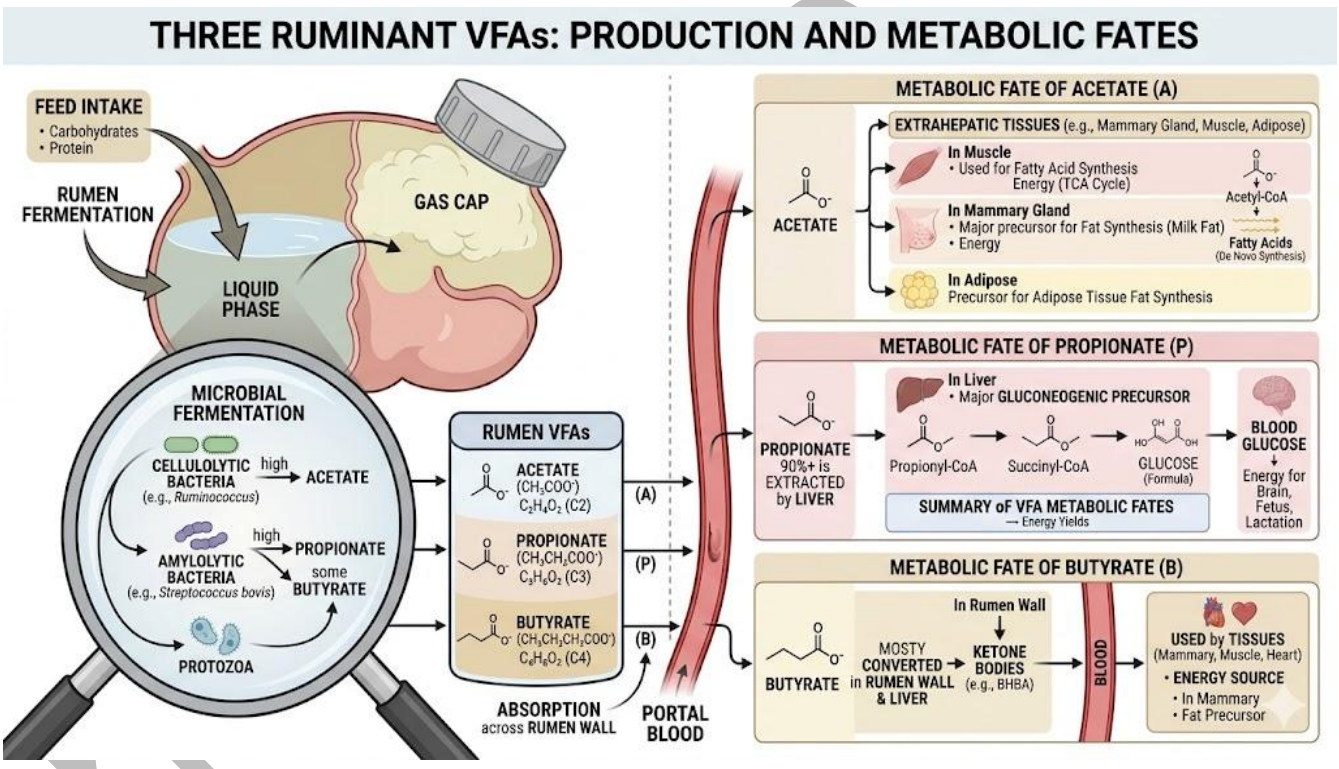


Figure 3.6: Diagram showing the fate of rumen VFAs in the ruminant body

Pilot questions 3.2

1. Name the four chambers of the ruminant stomach and state the main function of each.
2. Explain the role of the oesophageal groove reflex in the newborn calf.
3. Name two cellulolytic bacteria in the rumen and explain their role.
4. Define rumination and explain why its cessation is clinically significant.

5. Name the three main VFAs produced in the rumen and state the primary metabolic use of each.

3.3 Monogastric Digestive Physiology

3.3.1 Digestion in the pig

The pig is the most important model monogastric in farm animal science and has a digestive system similar in plan to other simple-stomached mammals. Feed enters the mouth, where mechanical breakdown and salivary amylase initiate starch digestion. Swallowing moves the bolus through the oesophagus to the stomach. The pig stomach secretes hydrochloric acid and pepsin for protein denaturation and hydrolysis. Gastric emptying into the duodenum is regulated by the pyloric sphincter and controlled by feedback from duodenal pH and fat content.

Compared with ruminants, pigs have limited capacity to ferment fibrous feeds because they lack a functional forestomach. However, pigs are highly efficient at digesting starch, sugar, and animal-derived proteins. Their relatively short digestive tract and rapid transit time allow intensive production on energy-dense diets. Understanding pig digestive anatomy guides diet formulation: insoluble fibre increases gut fill and satiety in sow management, while soluble fibre can support hindgut health by providing substrate for beneficial microorganisms.

Fill in the blank: Compared with ruminants, pigs have limited capacity to ferment _____ feeds because they lack a functional forestomach, but are highly efficient at digesting starch and high-quality proteins.

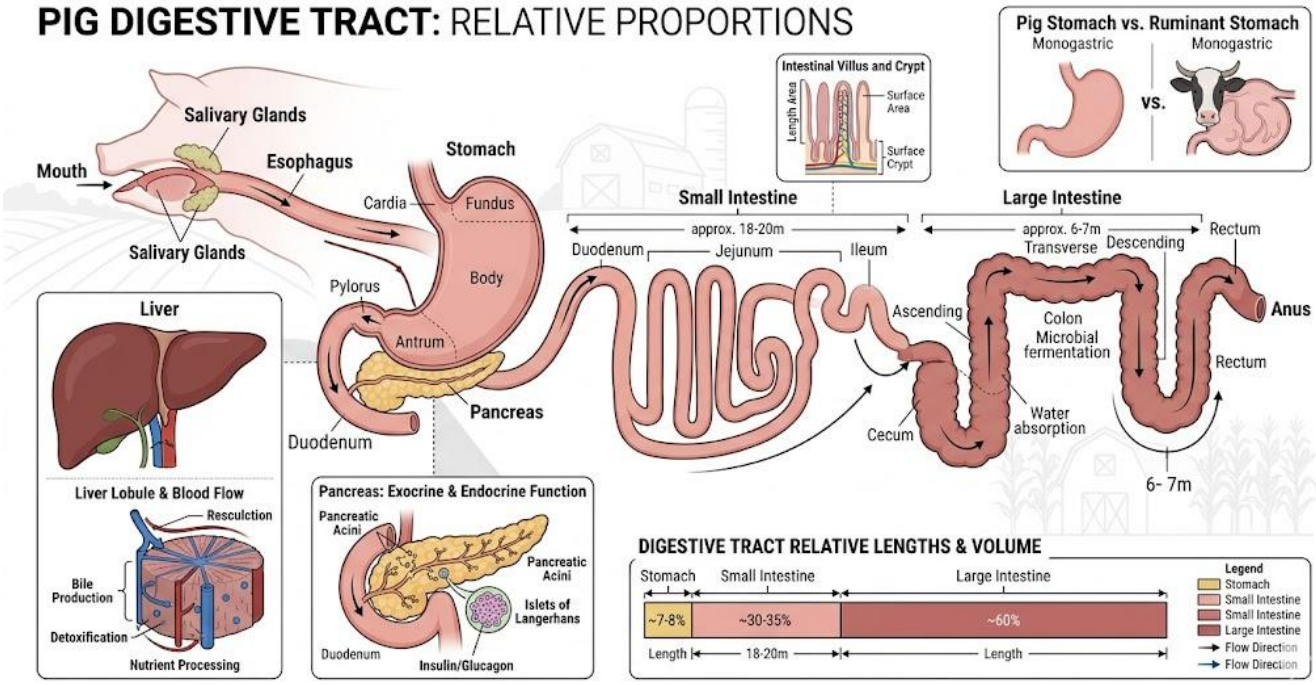


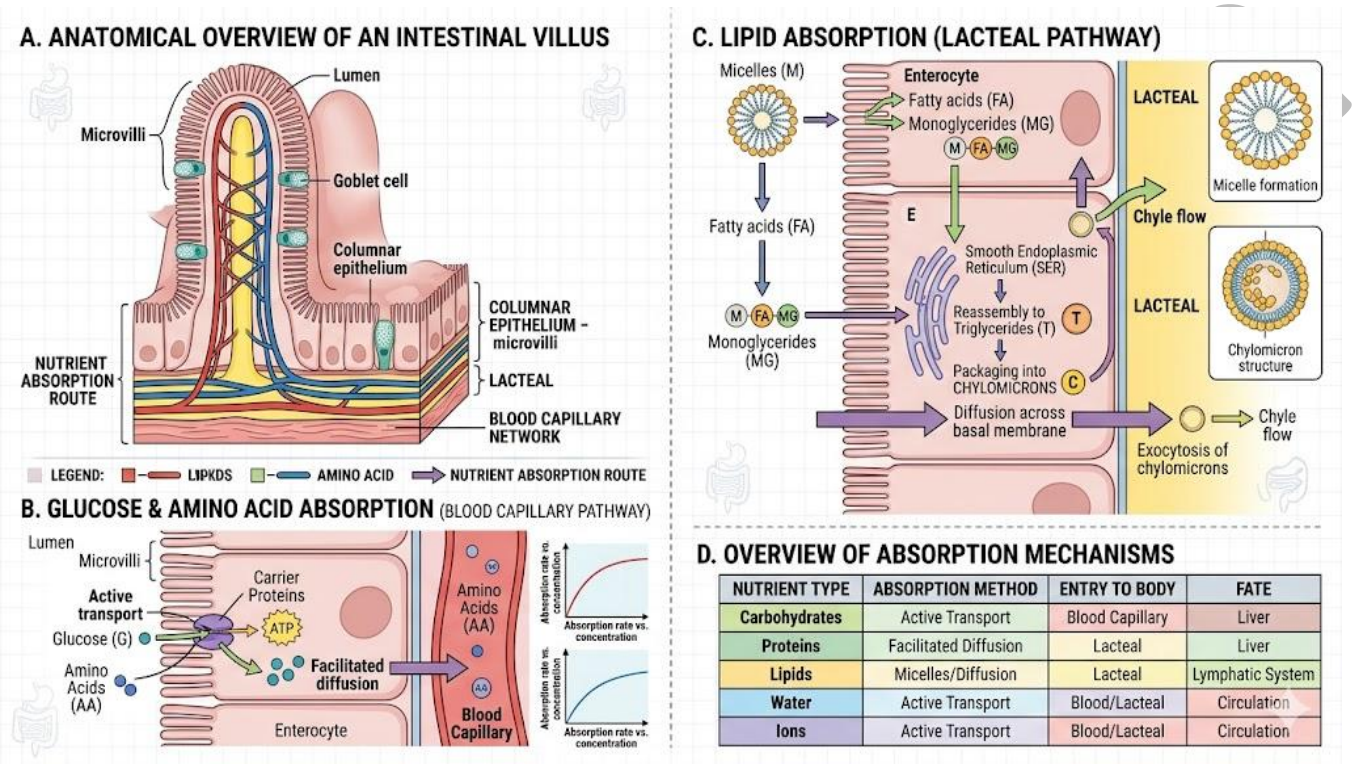
Figure 3.7: Diagram of the pig digestive tract showing all major organs with relative proportions

3.3.2 Digestive enzymes and nutrient absorption

Digestion in the small intestine relies on enzymes from three sources. Pancreatic enzymes secreted into the duodenum include pancreatic amylase (starch to maltose), pancreatic lipase (triglycerides to fatty acids and monoglycerides), and proteases (trypsin, chymotrypsin, elastase, and carboxypeptidases for protein hydrolysis). Bile from the liver emulsifies dietary fat, increasing lipase access to fat globules. Brush border enzymes on the intestinal epithelium complete digestion of disaccharides (sucrase, maltase, lactase) and dipeptides.

Absorbed nutrients enter different routes. Glucose, amino acids, and water-soluble vitamins are absorbed into the blood capillaries of the villus and transported via the portal vein to the liver. Fatty acids and fat-soluble vitamins are packaged into chylomicrons and absorbed into the lacteals (lymphatic capillaries) of the villi, entering the systemic circulation via the thoracic duct. The liver processes all absorbed nutrients from the portal blood, converting excess amino acids to glucose or urea, storing glycogen, and synthesising plasma proteins and lipoproteins.

Fill in the blank: Fatty acids and fat-soluble vitamins are absorbed into the _____ of intestinal villi and transported via the lymphatic system to the systemic circulation.



NUTRIENT TYPE	ABSORPTION METHOD	ENTRY TO BODY	FATE
Carbohydrates	Active Transport	Blood Capillary	Liver
Proteins	Facilitated Diffusion	Lacteal	Liver
Lipids	Micelles/Diffusion	Lacteal	Lymphatic System
Water	Active Transport	Blood/Lacteal	Circulation
Ions	Active Transport	Blood/Lacteal	Circulation

Figure 3.8: Diagram showing the routes of nutrient absorption from the intestinal villus

3.3.3 The large intestine and hindgut fermentation

The large intestine of the pig consists of the caecum, spiral colon, and rectum. Its primary function is water and electrolyte absorption from undigested ingesta. However, it also harbours a large microbial population that ferments undigested carbohydrates (resistant starch, non-starch polysaccharides, and dietary fibre) into short-chain fatty acids (SCFAs), which provide energy to the colonocytes and exert beneficial effects on gut health. Dietary fibre level strongly influences hindgut microbial composition and stool consistency.

The proportion of energy derived from hindgut fermentation in pigs is smaller than in ruminants (5 to 30 per cent depending on dietary fibre level, versus 70 to 80 per cent in ruminants). Nevertheless, hindgut health is increasingly recognised as important for pig welfare, immunity, and performance. Disruption of the hindgut microbiome by antibiotics or highly digestible diets

can increase susceptibility to post-weaning diarrhoea caused by pathogenic Escherichia coli. Feeding dietary fibre and prebiotics can restore microbial balance and reduce enteric disease.

Fill in the blank: The pig large intestine ferments undigested carbohydrates into _____ fatty acids, which provide energy to colonocytes and support gut health.

Animal group	Stomach type	Fibre digestion ability	Fermentation energy %	Optimal diet
Ruminants	Multi-chambered (rumen, reticulum, omasum, abomasum)	High (extensive microbial breakdown of cellulose)	60–70% of energy from fermentation	Forage-based diets (grass, hay, silage)
Pigs	Simple monogastric stomach	Moderate (limited hindgut fermentation)	10–20% of energy from fermentation	Balanced grain-based diets with some fibre
Poultry	Simple monogastric stomach with crop and gizzard	Very low (minimal fibre digestion)	<5% of energy from fermentation	Concentrated grain and protein-rich diets

Box 3.1: Comparison of digestive efficiency in ruminants, pigs, and poultry

Pilot questions 3.3

1. Explain why pigs are more efficient than ruminants at digesting starch but less efficient at digesting fibre.
2. Name the three sources of digestive enzymes acting in the pig small intestine.
3. Explain the role of bile in fat digestion.
4. Distinguish between the blood and lymphatic routes of nutrient absorption from the intestinal villus.
5. Explain how dietary fibre influences pig hindgut health.

3.4 Avian Digestive Physiology

3.4.1 Unique features of the avian digestive tract

The avian digestive tract is adapted for a high feed intake relative to body weight, rapid transit, and efficient nutrient extraction from grain-based diets. Birds lack teeth; mechanical reduction of feed relies on the muscular gizzard. The digestive tract is relatively short and transit time is fast (2 to 4 hours in broilers), requiring highly digestible, energy-dense diets. Birds also lack a urinary bladder; urine and faeces are expelled together through the cloaca.

The avian digestive tract is also characterised by paired caeca that harbour bacterial fermentation, a paired pancreas lying between the duodenal loops, and a liver with two lobes each draining via its own bile duct into the duodenum. Some species (chickens) have a gallbladder; others (pigeons, ostriches) do not. The absence of teeth and the compact body plan reduce body weight, which is important for flight in wild species and for feed conversion efficiency in commercial poultry.

Fill in the blank: Birds lack teeth and rely on the muscular _____ to grind feed mechanically; transit time through the avian digestive tract is approximately 2 to 4 hours in broilers.

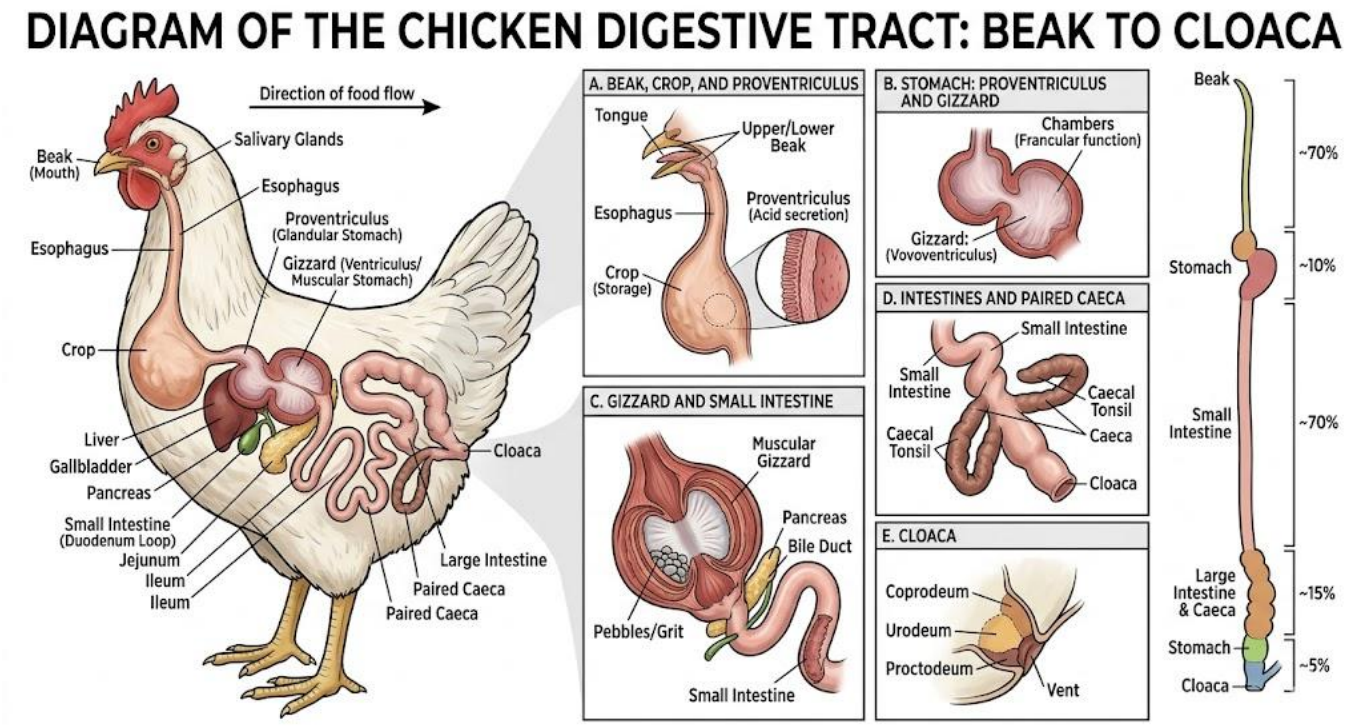


Figure 3.9: Diagram of the avian digestive tract from beak to cloaca showing all major organs

3.4.2 The crop, proventriculus, and gizzard

The crop is a diverticulum of the oesophagus that stores feed and allows controlled release to the rest of the tract; it also initiates softening and limited microbial fermentation of ingesta. The proventriculus (glandular stomach) secretes hydrochloric acid and pepsinogen for protein denaturation; it is equivalent to the mammalian stomach but does not store feed. Feed spends only seconds in the proventriculus before passing to the gizzard.

The gizzard (muscular stomach, ventriculus) is a powerful grinding organ with a thick muscular wall and a hard keratinised inner lining (koilin) that protects the muscle from abrasion. Its strong rhythmic contractions (2 to 3 per minute) grind feed particles against the koilin surface and against grit (small stones ingested by the bird), reducing particle size and increasing surface area for enzymatic attack. Well-developed gizzard function improves feed digestibility, particularly for whole grain diets; underutilisation leads to gizzard atrophy.

Fill in the blank: The avian _____ is a powerful muscular grinding organ with a keratinised inner lining (koilin) that reduces feed particle size by rhythmic contractions against ingested grit.

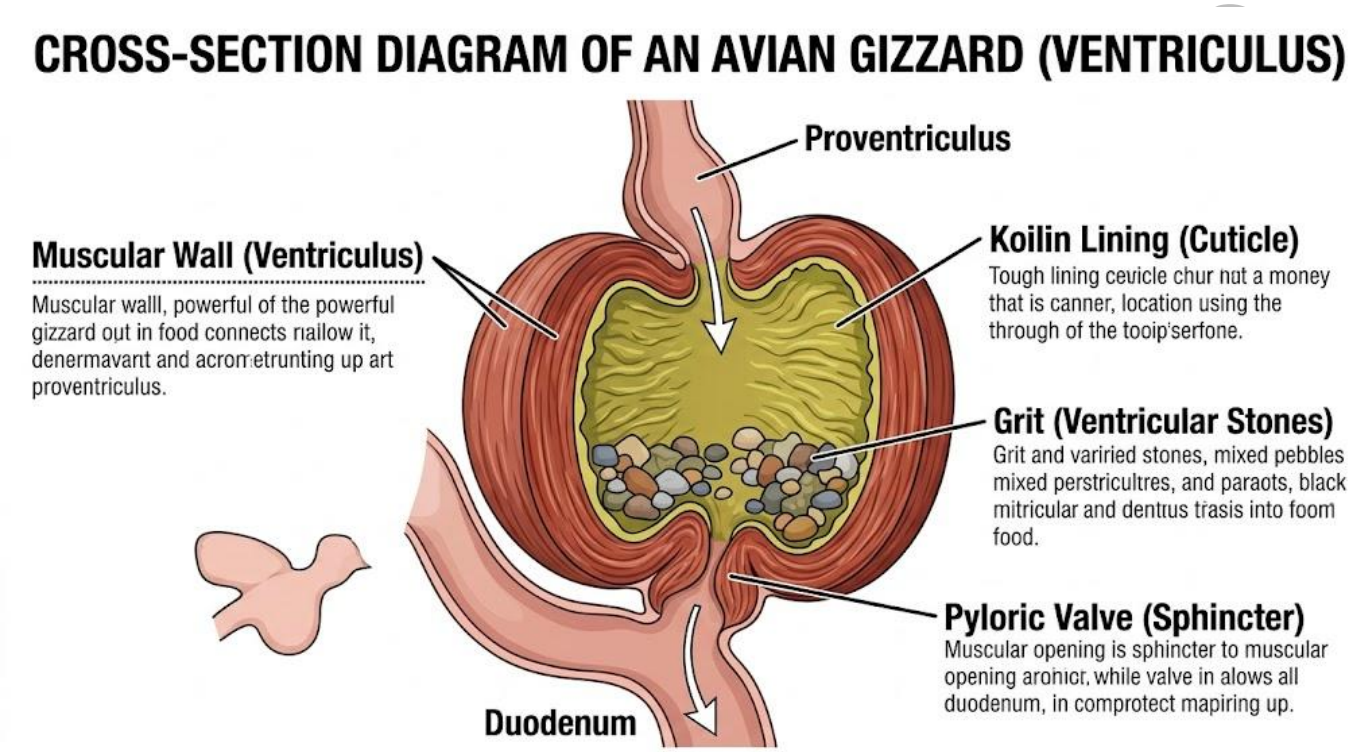


Figure 3.10: Cross-section diagram of the avian gizzard showing the muscular wall, koilin lining, and grit

3.4.3 The avian intestines and cloaca

The avian small intestine performs the same functions as in mammals: enzymatic digestion of starch, protein, and fat, and absorption of nutrients across the villus epithelium. The pancreas secretes amylase, lipase, and proteases into the duodenum; the liver supplies bile via the bile ducts. The paired caeca at the ileorectal junction harbour anaerobic bacterial fermentation of undigested material, producing SCFAs and B vitamins; they also play an important role in water reabsorption and immune function.

The colorectum is short in birds; water reabsorption from urine and intestinal contents is efficient. The cloaca is a common chamber receiving the products of the intestinal, urinary, and reproductive tracts. It is divided into three compartments: the coprodaeum (receives faeces), the

urodaeum (receives urine from the ureters and reproductive ducts), and the proctodaeum (the chamber leading to the vent). In laying hens, the egg enters the cloaca through the proctodaeum at the time of laying.

Fill in the blank: The avian cloaca is a common chamber divided into the coprodaeum (faeces), the _____ (urine and reproductive products), and the proctodaeum (vent chamber).

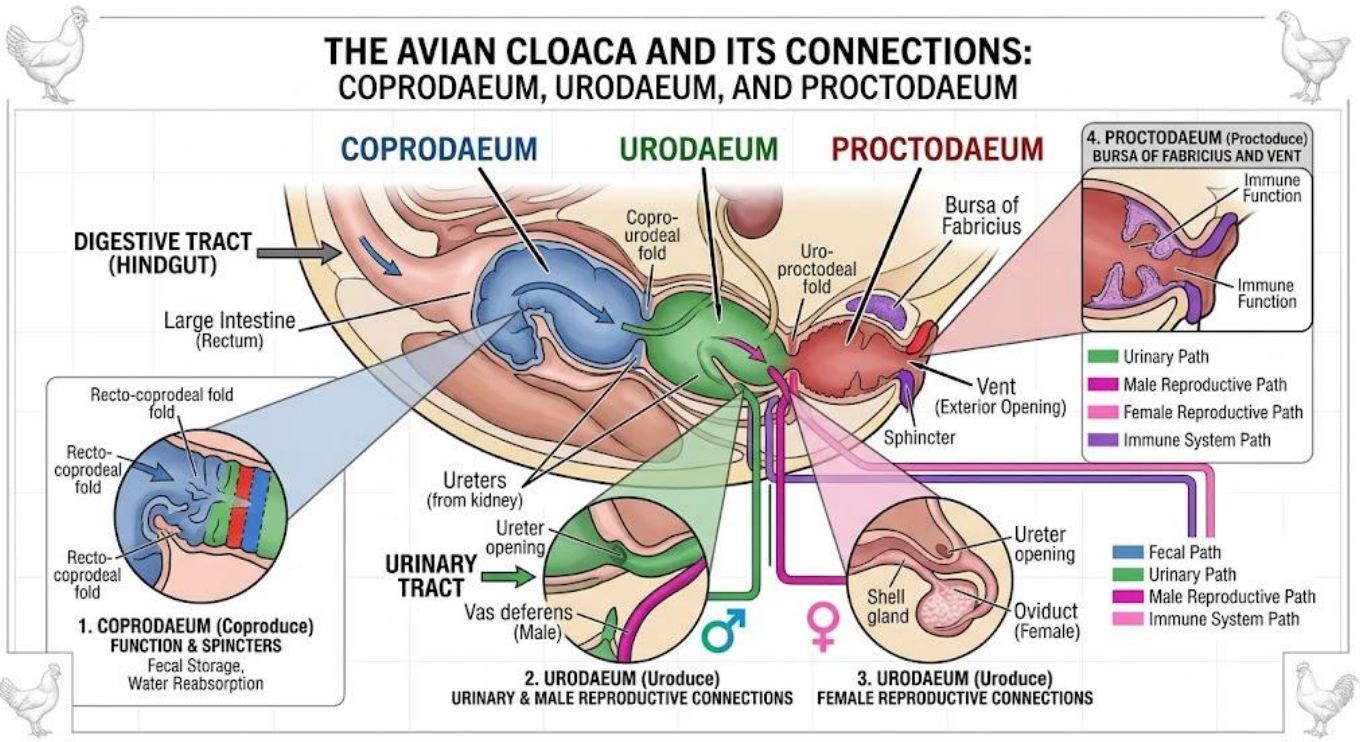


Figure 3.11: Diagram showing the three compartments of the avian cloaca and their connections to the digestive, urinary, and reproductive tracts

Pilot questions 3.4

6. State three ways in which the avian digestive tract differs from the mammalian tract.
7. Describe the function of the crop and explain why it is important for poultry management.
8. Explain how the gizzard grinds feed and why grit is important.
9. Name the three compartments of the cloaca and state what each receives.
10. Explain the function of the paired avian caeca.

Series Summary

This Series described the digestive physiology of mammals and birds. We began with the general mammalian tract, covering its four wall layers, the role of the stomach in protein digestion, and the amplified absorptive surface of the small intestine. We then examined ruminant digestion in detail, describing the four chambers, the rumen microbial community, the products of fermentation (VFAs, microbial protein, gases), the process of rumination, and the dangers of bloat when eructation fails.

We then covered monogastric digestion in the pig, comparing it with the ruminant, explaining enzyme sources and nutrient absorption routes, and describing hindgut fermentation and its role in gut health. Finally, we described the avian digestive system, highlighting the crop, proventriculus, gizzard, paired caeca, and the cloaca as the terminal common chamber of the intestinal, urinary, and reproductive tracts. By completing this Series, you should be able to achieve all nine Series Learning Outcomes (SLO 3.1 to SLO 3.9).

Glossary of Terms

- **Abomasum:** the fourth chamber of the ruminant stomach; the true glandular stomach equivalent to the monogastric stomach; secretes HCl and pepsin.
- **Bile:** secretion of the liver that emulsifies dietary fat in the small intestine, increasing lipase access to fat globules.
- **Bloat:** accumulation of gas (CO_2 and methane) in the rumen due to failure of eructation; can be fatal if not relieved.
- **Brush border:** the dense layer of microvilli on the apical surface of intestinal epithelial cells that amplifies absorptive surface area and carries digestive enzymes.
- **Caecum (avian):** one of a pair of fermentation pouches at the ileorectal junction of birds; harbours anaerobic fermentation and water absorption.
- **Chylomicron:** lipoprotein particles assembled in intestinal cells to transport dietary fat and fat-soluble vitamins into the lacteals.

- **Cloaca:** the common terminal chamber in birds receiving products of the intestinal, urinary, and reproductive tracts; divided into coprodaeum, urodaeum, and proctodaeum.
- **Crop:** a diverticulum of the oesophagus in birds that stores feed, initiates softening, and controls feed release to the proventriculus and gizzard.
- **Eructation:** the belching of rumen gases (CO_2 and methane) via the oesophagus; failure causes bloat.
- **Gizzard (ventriculus):** the muscular grinding stomach of birds, with a thick muscular wall and keratinised koilin inner lining; grinds feed by rhythmic contractions against ingested grit.
- **Hardware disease (traumatic reticuloperitonitis):** inflammation of the reticulum and peritoneum caused by a swallowed metal foreign body; common in cattle.
- **Koilin:** the hard keratinised inner lining of the avian gizzard that protects the muscular wall from abrasion during grinding.
- **Lacteal:** a lymphatic capillary in the core of an intestinal villus that absorbs chylomicrons carrying dietary fat and fat-soluble vitamins.
- **Microbial protein:** protein in the bodies of rumen microorganisms (bacteria, protozoa, fungi) that passes from the rumen to the abomasum and small intestine where it is digested and absorbed; provides 50 to 80 per cent of the amino acid supply of ruminants.
- **Oesophageal groove:** a reflex in the newborn ruminant that closes the reticular groove, directing milk from the oesophagus directly to the abomasum and bypassing the undeveloped rumen and reticulum.
- **Omasum:** the third chamber of the ruminant stomach, consisting of leaf-like lamellae that absorb water and VFAs while grinding and squeezing digesta.
- **Pepsin:** a proteolytic enzyme secreted as pepsinogen by the gastric mucosa and activated by hydrochloric acid; begins protein hydrolysis in the stomach.
- **Peristalsis:** the coordinated wave of smooth muscle contraction in the digestive tract wall that propels ingesta along the tract.
- **Proventriculus:** the glandular (true) stomach of birds that secretes HCl and pepsinogen; equivalent to the mammalian stomach but lacks storage function.

- **Reticulum:** the second chamber of the ruminant stomach, cranioventral and lined with a honeycomb mucosa; the site where ingested foreign objects accumulate.
- **Rumen:** the largest chamber of the ruminant stomach; a fermentation vat containing bacteria, protozoa, and fungi that digest cellulose and other carbohydrates.
- **Rumination:** the process of regurgitating coarse rumen contents, re-chewing them, and re-swallowing; essential for reducing particle size and efficient rumen fermentation.
- **Short-chain fatty acids (SCFAs):** fermentation products of the hindgut (and rumen in ruminants); include acetate, propionate, and butyrate; provide energy to colonocytes and support gut health.
- **Volatile fatty acids (VFAs):** the main fermentation products of the rumen: acetate (energy, fat synthesis), propionate (gluconeogenesis), and butyrate (colonocyte energy and rumen papillae development).
- **Villi:** finger-like projections of the intestinal mucosa that increase absorptive surface area; each contains a central lacteal and blood capillaries.

Concept Check Questions [Series 3]

Objective Questions

1. The wall of the digestive tract has four layers; the outermost layer is the _____. (Linked to SLO 3.1)
2. The true glandular stomach of ruminants, equivalent to the monogastric stomach, is the _____. (Linked to SLO 3.4)
3. The three main VFAs produced in the rumen are acetate, butyrate, and _____, which is the precursor for glucose synthesis. (Linked to SLO 3.5)
4. Fatty acids and fat-soluble vitamins are absorbed into the _____ of the intestinal villus. (Linked to SLO 3.7)
5. The avian _____ is the muscular grinding organ with a keratinised koilin lining that reduces feed particle size. (Linked to SLO 3.8)

Short-Answer Questions

1. Describe the functions of the four chambers of the ruminant stomach. (Linked to SLO 3.4)
2. Explain rumen fermentation: what organisms are involved and what are the main products? (Linked to SLO 3.5)
3. Explain what rumination is and why its cessation is clinically important. (Linked to SLO 3.6)
4. Compare the routes of absorption of glucose and dietary fat from the small intestine. (Linked to SLO 3.7)
5. Describe the three compartments of the avian cloaca and their contents. (Linked to SLO 3.8)

Long-Answer Questions

1. Describe ruminant digestive physiology in detail, explaining the structure of the four chambers, the rumen microbial community and its benefits, the process of rumination, the VFAs produced and their metabolic fates, and the clinical consequences of rumen dysfunction. (Linked to SLOs 3.4, 3.5, 3.6)
2. Compare digestion in ruminants, monogastrics (pig), and birds, highlighting the structural and functional differences that determine the type of diet each species is best suited to digest. (Linked to SLOs 3.4, 3.7, 3.8, 3.9)

Answers to Concept Check Questions [Series 3]

Objective Questions

1. Serosa.
2. Abomasum.
3. Propionate.
4. Lacteals.
5. Gizzard.

Short-Answer Questions

1. Rumen: large fermentation chamber; bacteria, protozoa, and fungi ferment cellulose, hemicellulose, and starch. Reticulum: cranioventral, honeycomb mucosa; sorts digesta and traps ingested foreign objects. Omasum: leaf-like lamellae absorb water and VFAs and grind digesta. Abomasum: true glandular stomach; secretes HCl and pepsin to digest microbial and dietary protein.
2. The rumen contains bacteria (cellulolytic such as Fibrobacter succinogenes and Ruminococcus, amylolytic, and proteolytic), protozoa, and fungi. They ferment carbohydrates to VFAs (acetate, propionate, butyrate), CO2, and methane. They also synthesise microbial protein from ammonia and dietary nitrogen. VFAs are absorbed across the rumen wall and provide the majority of the ruminant's energy supply.
3. Rumination is the regurgitation of coarse rumen contents to the mouth, re-chewing to reduce particle size, mixing with saliva, and re-swallowing. It is essential because reducing particle size increases microbial surface area contact and rumen throughput. Cessation of rumination indicates rumen dysfunction (acidosis, impaction) or systemic illness and is one of the most reliable early clinical signs of disease in cattle.
4. Glucose and amino acids are absorbed across intestinal epithelial cells into blood capillaries of the villus and transported via the portal vein to the liver for processing. Dietary fatty acids and fat-soluble vitamins (A, D, E, K) are packaged into chylomicrons in intestinal cells, secreted into the lacteals (lymphatic capillaries), transported through the lymphatic system, and enter the systemic circulation via the thoracic duct, bypassing the liver initially.
5. Coprodaeum: receives faeces from the colorectum. Urodaeum: receives urine from the ureters and, in females, eggs or reproductive secretions from the oviduct. Proctodaeum: the terminal chamber leading to the vent (external opening); in laying hens, the egg is laid through the proctodaeum.

Long-Answer Questions

1. Rumen (fermentation, bacteria/protozoa/fungi, cellulose digestion); reticulum (digesta sorting, hardware disease site); omasum (water and VFA absorption, grinding); abomasum (HCl, pepsin, true digestion). Rumen microbiome: cellulolytic bacteria (Fibrobacter succinogenes, Ruminococcus), amylolytic, proteolytic; maintained at 38 to 42°C, pH 6 to 7,

anaerobic. Two major benefits: cellulose digestion and microbial protein synthesis (50 to 80% amino acid supply); urea supplementation possible. Rumination: regurgitation, re-chewing, re-swallowing; 6 to 10 hrs per day in cattle; cessation is clinical sign. VFAs: acetate (energy, fat), propionate (gluconeogenesis), butyrate (colonocyte energy, rumen papillae). Gas: CO2 and methane; eructation removes them; bloat if blocked.

2. Ruminants: four chambers, rumen fermentation, ability to digest cellulose, VFAs as main energy source (70 to 80% of energy from fermentation), suited to forage diets, urea usable as N source. Pigs: simple stomach, enzymatic digestion, highly efficient for starch and protein, limited fibre digestion (hindgut fermentation 5 to 30%), suited to grain and high-quality protein diets; hindgut fermentation supports gut health. Poultry: no teeth, crop stores and softens feed, proventriculus secretes acid, gizzard grinds feed, short transit (2 to 4 hrs), high feed intake relative to body weight, suited to grain diets, cloaca as common exit for faeces and urine; efficient but cannot utilise coarse fibre. Comparative significance: ruminants convert low-quality forages; pigs compete with humans for grain; poultry require high-quality diets but are highly efficient per unit meat or egg produced.

Answers to Pilot Questions [Series 3]

Part 3.1: The Mammalian Digestive System

1. Mouth, pharynx, oesophagus, stomach, small intestine, large intestine, rectum (anus as terminal).
2. Mucosa: inner epithelial lining; secretion and absorption. Submucosa: connective tissue with blood vessels and nerves; structural support. Muscularis: smooth muscle layers; peristalsis to propel ingesta. Serosa: outer peritoneal covering; protection and reduction of friction.
3. Gastric juice contains HCl (lowers pH to 1.5 to 3.5, denatures proteins and kills bacteria) and pepsinogen (activated to pepsin by HCl); pepsin hydrolyses proteins into large peptide fragments. The acidic environment also helps sterilise ingested feed and provides the optimal conditions for pepsin activity.
4. Duodenum: receives bile and pancreatic juice; site of most enzymatic digestion. Jejunum: the main site of nutrient absorption via villi and microvilli. Ileum: absorbs bile salts (enterohepatic circulation) and vitamin B12; completes absorption of remaining nutrients.

5. Three levels of amplification: circular folds (increase area 3-fold), villi (finger-like projections, increase area 10-fold), and microvilli forming the brush border on each villus cell (increase area 20-fold). Together they increase the effective absorptive surface area up to 600-fold compared with a plain tube of the same length.

Part 3.2: Ruminant Digestive Physiology

1. Rumen: large fermentation chamber containing bacteria, protozoa, and fungi that digest cellulose and other carbohydrates; main function is microbial fermentation. Reticulum: sorts digesta and traps foreign objects; lined with honeycomb mucosa; site of hardware disease. Omasum: leaf-like lamellae grind and squeeze digesta; absorbs water and VFAs. Abomasum: true glandular stomach; secretes HCl and pepsin; digests microbial and undegraded dietary protein.
2. In the newborn calf the rumen and reticulum are small and undeveloped; the oesophageal groove is a muscular reflex that closes when milk enters the mouth, forming a tube that bypasses the rumen and reticulum and delivers milk directly to the omasum and abomasum for enzymatic digestion. This is essential because milk would be rapidly fermented and wasted if it entered the rumen. The reflex weakens as the rumen develops with solid feed intake.
3. Fibrobacter succinogenes and Ruminococcus spp. are the primary cellulolytic bacteria in the rumen. They produce cellulase enzymes that cleave the beta-1,4 glycosidic bonds of cellulose, breaking down plant cell walls into glucose units that are then fermented to VFAs. Without these bacteria, ruminants could not utilise grass, hay, silage, and other fibrous forages as energy sources.
4. Rumination is the cyclic process of regurgitation of coarse rumen contents (cud) to the mouth, re-mastication (chewing 40 to 60 times per cud bolus) to reduce particle size, mixing with buffering saliva, and re-swallowing. Cessation is clinically significant because it is one of the earliest and most reliable signs of rumen dysfunction (acidosis, bloat, impaction) or systemic disease (fever, pain); a cow that is not ruminating when resting is almost certainly unwell.
5. Acetate (most abundant, used as direct energy substrate and as acetyl-CoA precursor for fatty acid synthesis in adipose and mammary tissue). Propionate (converted to glucose via gluconeogenesis in the liver; the main gluconeogenic precursor in ruminants, which absorb

little glucose from the gut). Butyrate (oxidised by rumen epithelial cells for energy and stimulates development and proliferation of rumen papillae in growing animals).

Part 3.3: Monogastric Digestive Physiology

1. Pigs digest starch more efficiently than ruminants because they produce their own pancreatic amylase and intestinal brush-border glucosidases that directly hydrolyse starch to glucose for rapid absorption in the small intestine, without requiring microbial fermentation. They are less efficient at digesting fibre because they lack a functional forestomach with cellulolytic microorganisms; only limited hindgut fermentation of non-starch polysaccharides occurs in the large intestine.
2. Three sources: (1) pancreatic secretions (amylase, lipase, trypsin, chymotrypsin, elastase, carboxypeptidases) secreted into the duodenum from the exocrine pancreas; (2) bile from the liver (emulsifies fat for lipase action; not an enzyme but essential for fat digestion); (3) brush border enzymes on the intestinal epithelium (maltase, sucrase, lactase, peptidases completing the digestion of disaccharides and dipeptides).
3. Dietary fat arrives in the small intestine as large lipid droplets that have a small surface area for lipase attack. Bile, secreted by the liver and stored in the gallbladder (in pigs), is released into the duodenum and acts as a detergent, breaking large fat droplets into tiny emulsified droplets (emulsification). This dramatically increases the surface area available to pancreatic lipase, greatly accelerating triglyceride hydrolysis to fatty acids and monoglycerides that can be absorbed.
4. Glucose and amino acids from carbohydrate and protein digestion cross the intestinal epithelium and enter blood capillaries in the villus core; they are transported via the portal vein directly to the liver for processing. Dietary fatty acids and fat-soluble vitamins (A, D, E, K) are assembled into chylomicrons within intestinal epithelial cells, secreted into the lacteals (lymphatic capillaries in the villus core), and travel through the lymphatic system, entering the blood at the thoracic duct without passing through the liver initially.
5. Dietary fibre that escapes small intestinal digestion reaches the large intestine, where it is fermented by the resident microbial community to SCFAs including butyrate, propionate, and acetate. Butyrate is the preferred energy source of colonocytes and promotes intestinal epithelial health and barrier function. Fermentable fibre also supports beneficial bacterial

species (Lactobacillus, Bifidobacterium) that compete with pathogens, reducing the risk of post-weaning diarrhoea caused by enterotoxigenic Escherichia coli.

Part 3.4: Avian Digestive Physiology

1. Any three: birds lack teeth and rely on the gizzard for mechanical feed reduction; birds have a crop (feed storage and softening) absent in mammals; birds have a proventriculus as a separate glandular stomach before the gizzard; birds have a short digestive tract with fast transit time (2 to 4 hours); birds have paired caeca for hindgut fermentation; birds have a cloaca as a common exit for faeces, urine, and reproductive products; birds excrete uric acid in urine combined with faeces rather than urea.
2. The crop is a diverticulum (pouch) off the oesophagus between the oesophagus and proventriculus. Its functions are: temporary storage of ingested feed, allowing the bird to eat rapidly and process feed over a longer period; initiation of feed softening and partial starch digestion by salivary amylase; and limited microbial fermentation that can support lactobacilli. In poultry management, crop health is important: impacted crop (failure to empty) causes production loss; sour crop (Candida infection) causes chronic illness.
3. The gizzard is a thick-walled muscular organ lined internally with a hard keratinised layer called koilin. The gizzard contracts rhythmically (2 to 3 times per minute) with great force, compressing and rotating its contents. Feed particles are ground between the koilin surfaces and against grit (small stones ingested by the bird). Grit is important because the abrasive surface it provides greatly increases grinding efficiency for whole grains; birds without access to grit have poorer digestibility of whole grain diets.
4. Coprodaeum: the cranial compartment; receives faeces from the colorectum. Urodaeum: the middle compartment; receives urine from the ureters and, in females, the oviduct (which delivers eggs during laying). Proctodaeum: the caudal compartment; the common chamber leading to the vent (external opening) through which all waste and reproductive products are expelled.
5. The paired avian caeca are pouches at the junction of the ileum and colorectum. They receive material from both the ileum and colorectum and harbour anaerobic bacterial fermentation of undigested material, producing SCFAs and B vitamins. They also play a key role in water reabsorption and host a significant immune cell population that contributes to mucosal

defence. In turkeys, the caeca are well-developed and contribute substantially to energy recovery from fibre.

References and Attributions [Series 3]

Textual References (Books and External Sources)

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Figures, Plates, Tables, and Boxes

- Figure 3.1: Mammalian digestive tract Attribution: AI generated. Suggested OER search string: "mammalian digestive tract labelled diagram mouth stomach intestines OER".
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- Figure 3.6: Rumen VFA metabolic fates Attribution: AI generated. Suggested OER search string: "rumen VFA acetate propionate butyrate metabolic fates ruminant OER".

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- Figure 3.11: Avian cloaca compartments Attribution: AI generated. Suggested OER search string: "avian cloaca coprodaeum urodaeum proctodaeum connections OER diagram".

Course code: AGE 204

Course title: Anatomy and Physiology of Farm Animals

Course credit load: 2 Units

Series 4: Circulatory, Lymphatic, Urinary, and Nervous Systems in Farm Animals

- **Part 4.1: The Cardiovascular System**
  - Sub Part 4.1.1: Structure and function of the heart
  - Sub Part 4.1.2: Blood vessels and circulation
  - Sub Part 4.1.3: Blood composition and functions
- **Part 4.2: The Lymphatic System**
  - Sub Part 4.2.1: Components and functions of the lymphatic system
  - Sub Part 4.2.2: Lymph nodes and lymphoid organs
  - Sub Part 4.2.3: Immune defence and the lymphatic system
- **Part 4.3: The Urinary System**
  - Sub Part 4.3.1: Structure of the kidney and nephron
  - Sub Part 4.3.2: Urine formation
  - Sub Part 4.3.3: The ureters, urinary bladder, and urethra
- **Part 4.4: The Nervous System**
  - Sub Part 4.4.1: Organisation of the nervous system
  - Sub Part 4.4.2: The neuron and nerve impulse
  - Sub Part 4.4.3: The autonomic nervous system

Introduction

The cardiovascular, lymphatic, urinary, and nervous systems are the four great integrating and regulatory systems of the animal body. The cardiovascular system distributes nutrients, oxygen, hormones, and waste products to every cell; the lymphatic system drains excess tissue fluid and mounts immune defences; the urinary system removes metabolic waste and regulates fluid, electrolyte, and acid-base balance; and the nervous system coordinates all body functions and mediates responses to the environment.

The aim of this Series is to describe the structure and function of the heart and blood vessels, the components of the lymphatic and immune system, the anatomy and physiology of the kidney and urine formation, and the organisation of the nervous system from the neuron to the autonomic control of farm animal physiology. We shall cover each system in turn, drawing connections to animal production and health throughout.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 4.1** describe the structure and function of the heart and explain the cardiac cycle (Linked to Part 4.1),
- **SLO 4.2** distinguish between arteries, capillaries, and veins, and describe the pulmonary and systemic circulations (Linked to Part 4.1),
- **SLO 4.3** describe the components of blood and explain their functions (Linked to Part 4.1),
- **SLO 4.4** describe the components and functions of the lymphatic system (Linked to Part 4.2),
- **SLO 4.5** explain the role of lymph nodes and lymphoid organs in immune defence (Linked to Part 4.2),
- **SLO 4.6** describe the structure of the kidney and the nephron (Linked to Part 4.3),
- **SLO 4.7** explain the three processes of urine formation: filtration, reabsorption, and secretion (Linked to Part 4.3),
- **SLO 4.8** describe the organisation of the nervous system and the structure of the neuron (Linked to Part 4.4), and

- **SLO 4.9** explain the autonomic nervous system and its role in regulating farm animal physiology (Linked to Part 4.4).

4.1 The Cardiovascular System

4.1.1 Structure and function of the heart

The heart is a four-chambered muscular pump that maintains continuous blood circulation. The right atrium and right ventricle receive deoxygenated blood from the body and pump it to the lungs (pulmonary circulation). The left atrium and left ventricle receive oxygenated blood from the lungs and pump it to the rest of the body (systemic circulation). The two sides are separated by the interventricular septum. The atria receive blood; the ventricles eject it. The left ventricular wall is thicker than the right because it must generate higher pressure.

Four valves prevent backflow of blood: the atrioventricular valves (tricuspid on the right, bicuspid/mitral on the left) prevent backflow from ventricles to atria, and the semilunar valves (pulmonary and aortic) prevent backflow from the great vessels into the ventricles. The cardiac cycle consists of systole (ventricular contraction and ejection) and diastole (ventricular relaxation and filling). Heart rate in adult cattle is 60 to 80 beats per minute; in chickens it is 250 to 350 beats per minute, reflecting their higher metabolic rate.

Fill in the blank: The left ventricular wall is thicker than the right because it must generate higher pressure to drive blood through the _____ circulation to all parts of the body.

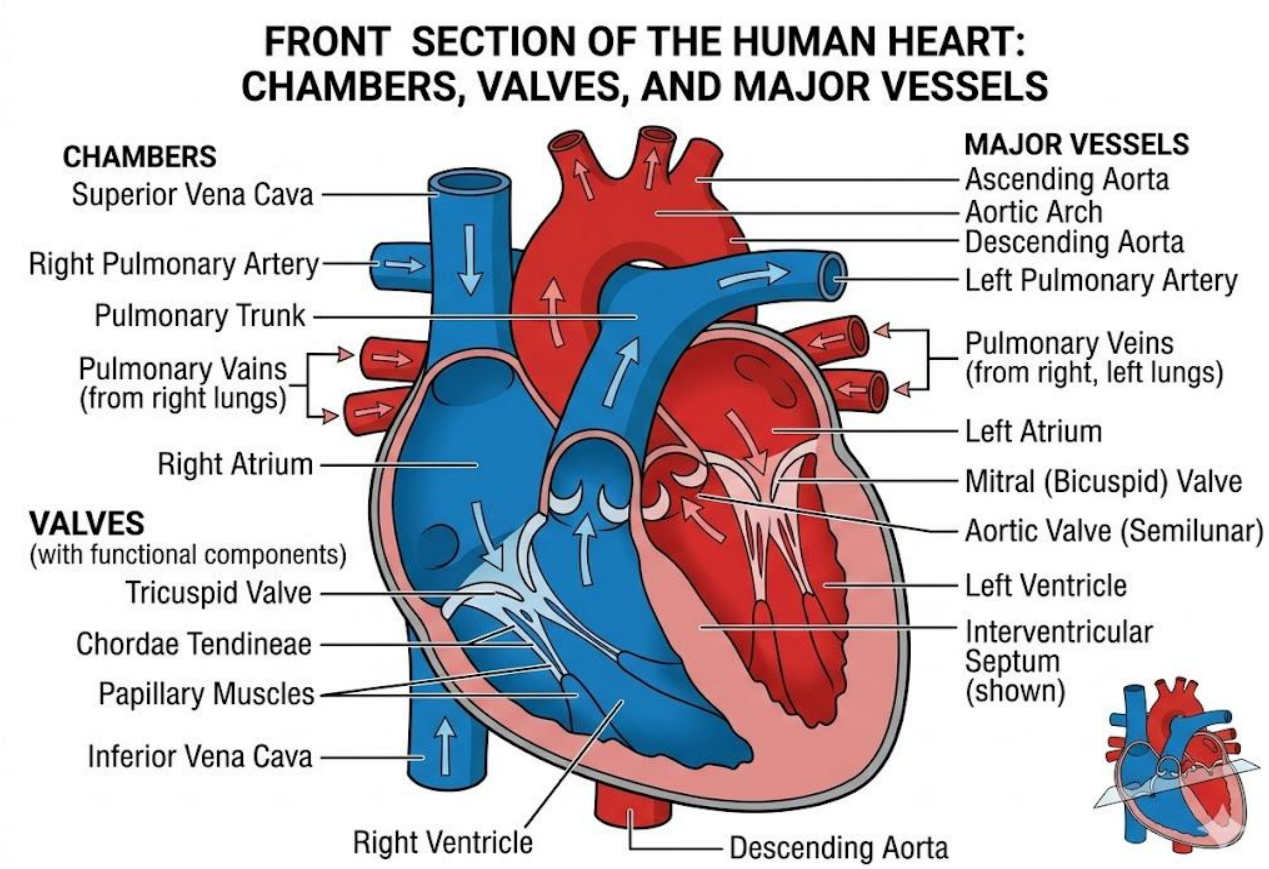

Figure 4.1: Diagram of the heart showing its four chambers, four valves, and major vessels

4.1.2 Blood vessels and circulation

Arteries carry blood away from the heart under high pressure. They have thick muscular and elastic walls that withstand and smooth out the pulsatile pressure of ventricular ejection. Arterioles are small arteries that regulate blood flow to individual organs by varying their diameter. Capillaries are the smallest vessels, with walls only one cell thick (endothelium); all nutrient, gas, and waste exchange between blood and tissues occurs across capillary walls. Veins return blood to the heart under low pressure; their thin walls contain valves that prevent backflow, especially in the limbs.

The systemic circulation carries oxygenated blood from the left ventricle via the aorta to all body organs, returning deoxygenated blood via the venae cavae to the right atrium. The pulmonary circulation carries deoxygenated blood from the right ventricle via the pulmonary artery to the lungs, returning oxygenated blood via the pulmonary veins to the left atrium. The portal

circulation is a special component of systemic circulation in which blood from the gastrointestinal tract and spleen drains through the portal vein to the liver before entering the general circulation.

Fill in the blank: All exchange of nutrients, gases, and waste between blood and tissues occurs across the walls of _____, which are one cell thick and found in every tissue of the body.

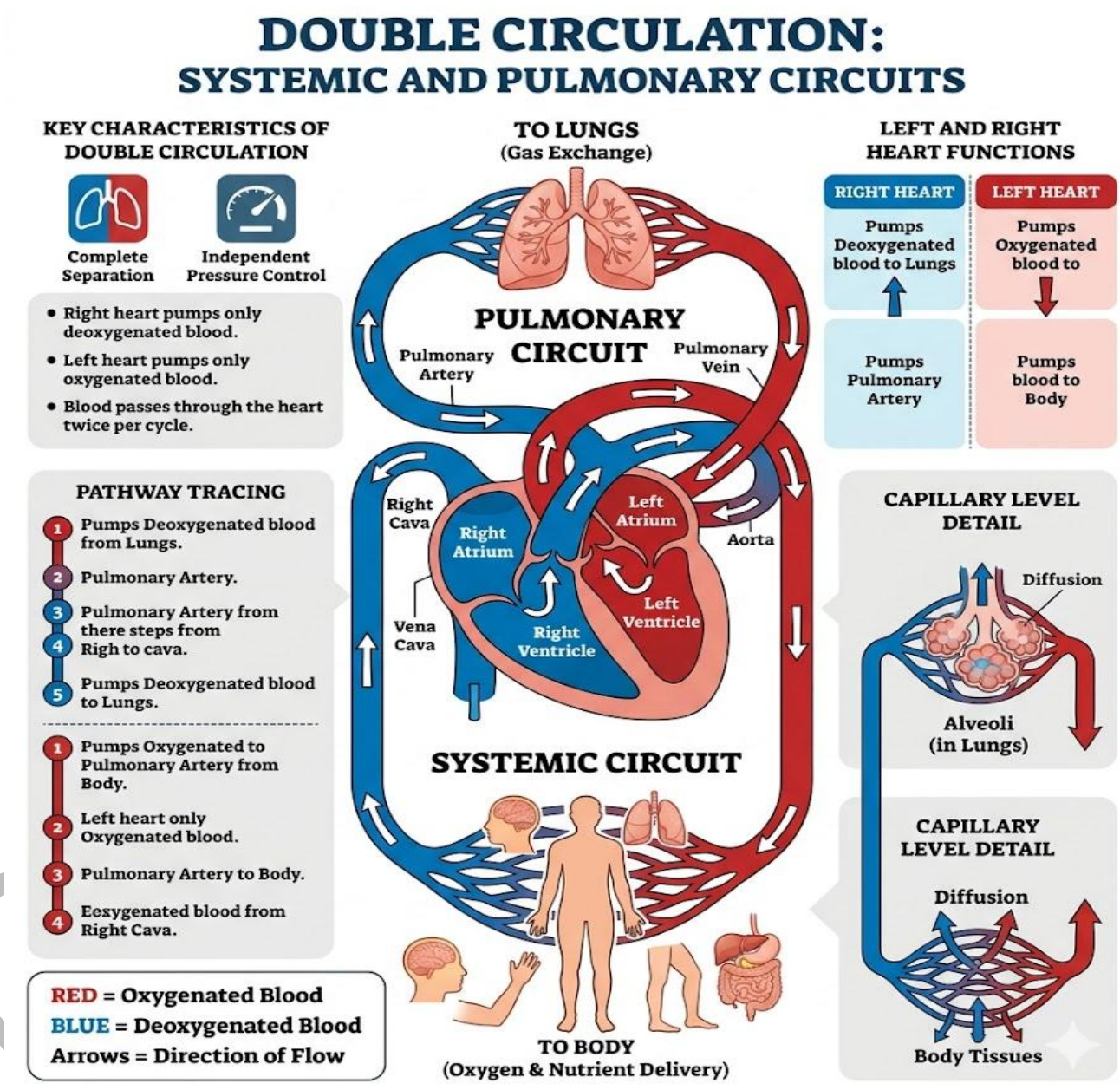

Figure 4.2: Diagram showing the pulmonary and systemic circulations

4.1.3 Blood composition and functions

Blood consists of plasma (55 per cent) and formed elements (45 per cent). Plasma is mostly water containing dissolved proteins (albumin, globulins, fibrinogen), nutrients, hormones, electrolytes, and waste products. The formed elements are: red blood cells (erythrocytes, which transport oxygen via haemoglobin and carbon dioxide), white blood cells (leucocytes, which defend against pathogens), and platelets (thrombocytes, which initiate blood clotting). Normal red blood cell count in cattle is 5 to 10 million per microlitre; in chickens it is 2.5 to 3.5 million per microlitre.

The functions of blood are: transport (oxygen, carbon dioxide, nutrients, hormones, waste products), regulation (body temperature through heat distribution, pH via buffer systems, osmotic pressure via plasma proteins), and protection (leucocytes and antibodies for immune defence, platelets and clotting factors for haemostasis). Anaemia is a reduction in circulating red blood cells or haemoglobin, reducing oxygen delivery to tissues; it is a common consequence of heavy parasite burdens in farm animals and causes pale mucous membranes, weakness, and reduced production.

Fill in the blank: Blood consists of _____ (approximately 55 per cent) and formed elements including red blood cells, white blood cells, and platelets.

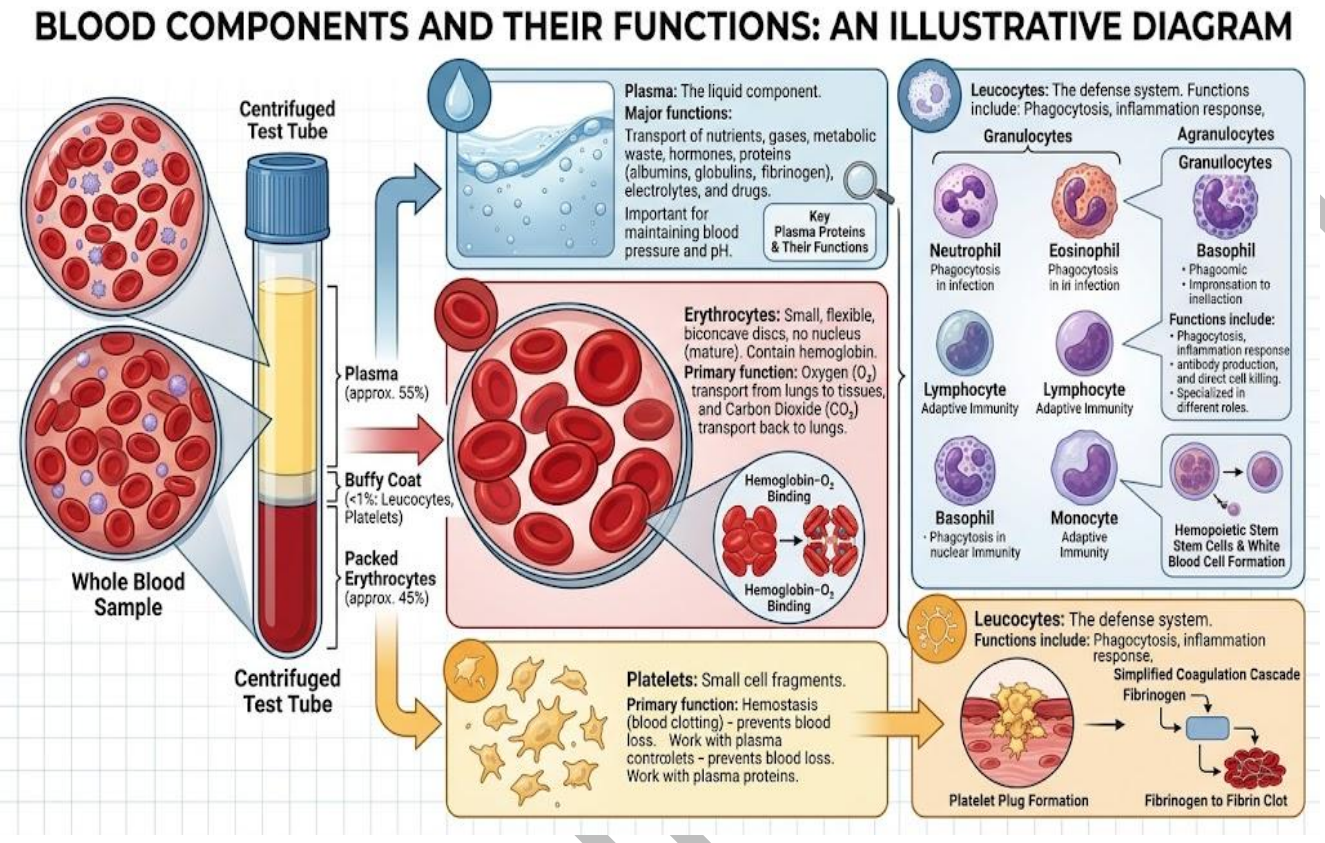

Figure 4.3: Diagram showing the components of blood and the functions of each fraction

Pilot questions 4.1

1. Describe the four chambers of the heart and explain the direction of blood flow through them.
2. Name the four heart valves and state the function of each.
3. Distinguish between arteries, capillaries, and veins in terms of structure and function.
4. Explain the portal circulation and state its significance for animal nutrition.
5. State three functions of blood and give one example of how each function supports animal production.

4.2 The Lymphatic System

4.2.1 Components and functions of the lymphatic system

The lymphatic system is a network of vessels, nodes, and lymphoid organs that performs three main functions: draining excess interstitial fluid back into the blood, transporting dietary fat from the intestine to the blood (via the lacteals and thoracic duct), and providing immune surveillance and defence. Lymph is the fluid that accumulates in the interstitial spaces as plasma leaks from blood capillaries; it is collected by blind-ended lymphatic capillaries and transported through progressively larger lymphatic vessels.

Lymph moves through the lymphatic vessels by the squeezing action of surrounding skeletal muscles and respiratory movements, assisted by one-way valves in the vessel walls. The thoracic duct is the main collecting vessel, draining lymph from most of the body into the left subclavian vein. The right lymphatic duct drains the right side of the head, neck, and thorax into the right subclavian vein. If lymphatic drainage is impaired (for example, by obstruction or parasitic infection), fluid accumulates in the tissues causing oedema.

Fill in the blank: The _____ duct is the main collecting vessel of the lymphatic system, draining lymph from most of the body into the left subclavian vein.

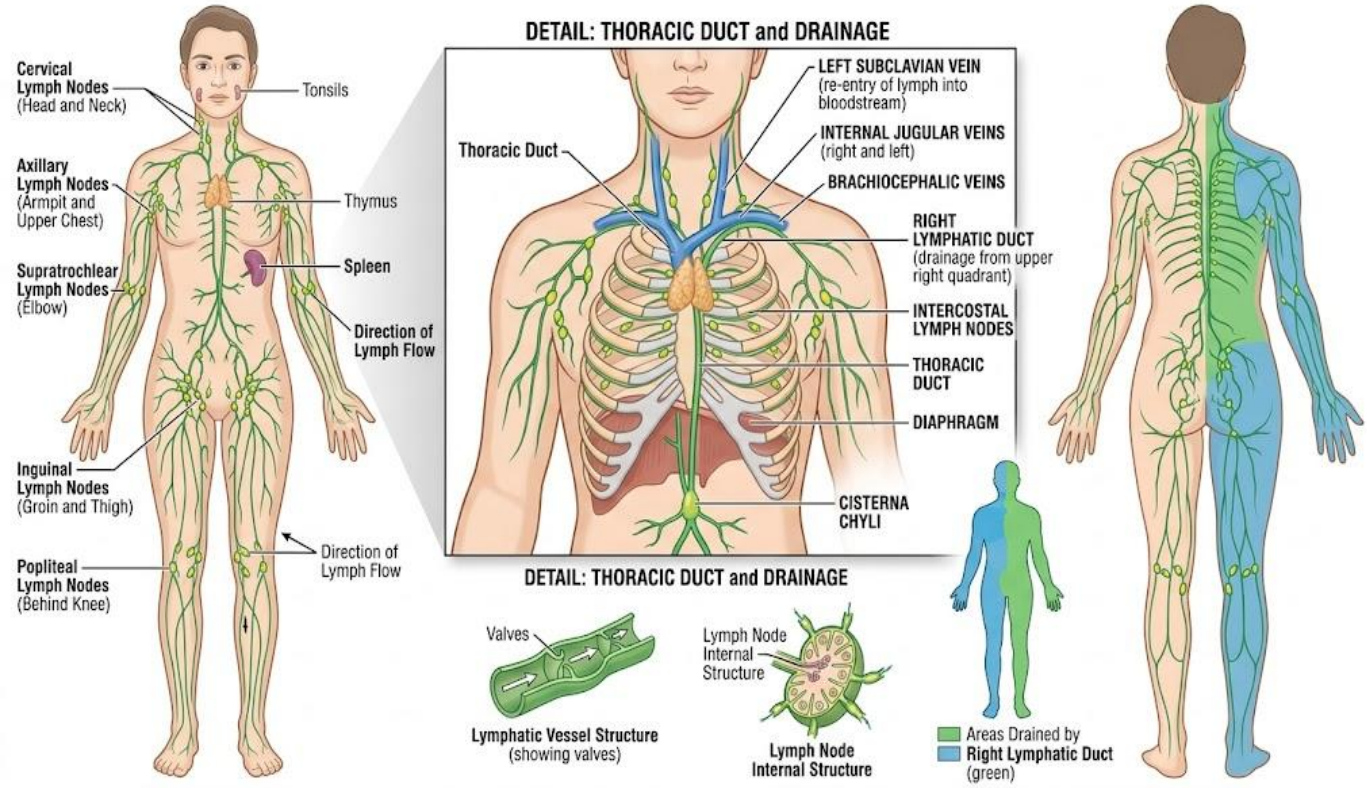

Figure 4.4: Diagram of the lymphatic system showing lymphatic vessels, major nodes, and the thoracic duct

4.2.2 Lymph nodes and lymphoid organs

Lymph nodes are small bean-shaped organs located along lymphatic vessels. Afferent lymphatic vessels bring lymph into the node; it percolates through the cortex (containing B lymphocytes in follicles) and paracortex (T lymphocytes) where pathogens and foreign particles are filtered out and immune responses are initiated; efferent lymphatic vessels carry lymph out of the node. Enlarged, painful lymph nodes (lymphadenopathy) indicate active infection or inflammation in the region they drain.

The major lymphoid organs of farm animals include the spleen (largest lymphoid organ; filters blood, removes aged red blood cells, and mounts immune responses to blood-borne antigens), thymus (site of T lymphocyte maturation; active in young animals, involutes at puberty), Peyer's patches (lymphoid follicles in the wall of the small intestine that monitor the gut contents for

antigens), and the bursa of Fabricius (a unique lymphoid organ in birds, dorsal to the cloaca, where B lymphocytes mature; regresses at sexual maturity).

Fill in the blank: The _____ of Fabricius is a unique lymphoid organ in birds where B lymphocytes mature; it is found dorsal to the cloaca and regresses at sexual maturity.

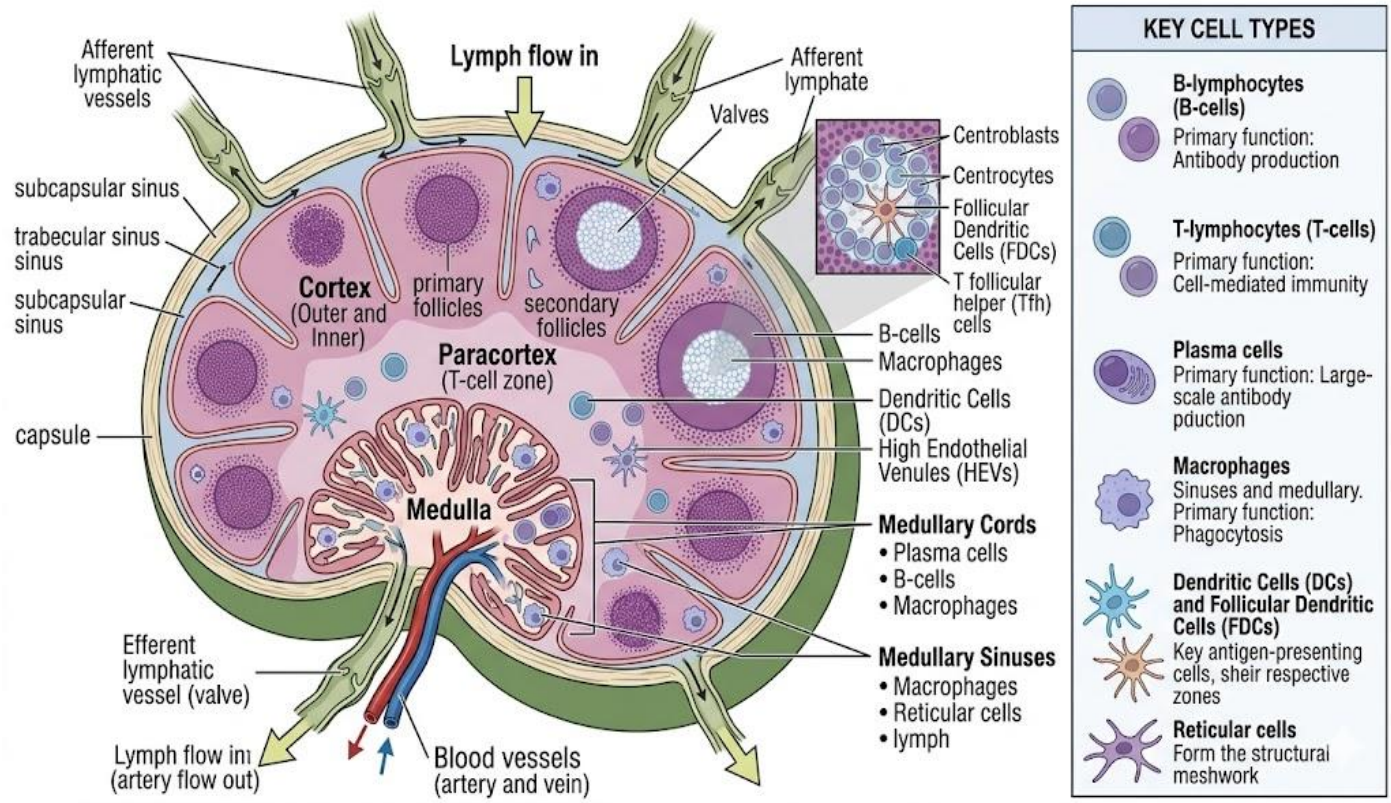

Figure 4.5: Cross-section diagram of a lymph node showing cortex, paracortex, medulla, and afferent and efferent vessels

4.2.3 Immune defence and the lymphatic system

The immune system is divided into innate (non-specific) and adaptive (specific) immunity. Innate immunity provides immediate but non-specific defence: skin and mucous membranes as physical barriers, phagocytic cells (neutrophils and macrophages) that engulf and destroy pathogens, natural killer cells, and the complement system. Adaptive immunity is pathogen-specific and takes days to weeks to develop but produces immunological memory. It involves B lymphocytes (producing antibodies) and T lymphocytes (cell-mediated killing of infected cells).

Passive immunity is the transfer of pre-formed antibodies from dam to offspring: in farm animals this occurs primarily via colostrum (the first milk), which is rich in immunoglobulins (IgG, IgA, IgM). Neonates absorb colostral antibodies intact across the intestinal epithelium for approximately 24 to 36 hours after birth (gut closure). Failure of passive transfer (inadequate colostrum intake) leaves the neonate without immune protection and dramatically increases susceptibility to septicaemia, scours, and joint ill.

Fill in the blank: Colostral antibodies are absorbed intact across the intestinal epithelium for approximately 24 to 36 hours after birth; after this period _____ closure prevents further antibody absorption.

Rule	Key Details
Timely feeding	Provide colostrum within the first 2 hours of life; gut absorption capacity declines rapidly after birth.
Adequate volume	Feed 10–12% of body weight in the first 24 hours (e.g., ~4 L for a 40 kg calf).
Quality assurance	Ensure colostrum has high immunoglobulin content (≥50 g/L IgG); test with colostrometer or Brix refractometer.
Clean collection	Collect colostrum hygienically to avoid bacterial contamination that reduces Ig absorption.
Proper storage	Refrigerate for short-term use or freeze for long-term; thaw gently to preserve antibodies.
Monitoring transfer	Check serum IgG or total protein in neonates at 24–48 hours to confirm successful passive transfer.

Box 4.1: Colostrum management for passive immunity in farm animals

Pilot questions 4.2

6. State the three main functions of the lymphatic system.
7. Explain how lymph moves through the lymphatic vessels.
8. Describe the structure of a lymph node and the cell types found in each zone.
9. Name four lymphoid organs and state the function of each.
10. Explain passive immunity and why colostrum intake within 24 hours of birth is critical.

4.3 The Urinary System

4.3.1 Structure of the kidney and nephron

The kidneys are paired bean-shaped organs located retroperitoneally (outside the peritoneum) in the dorsal abdomen. Cattle kidneys are lobulated (divided into distinct lobes); sheep, goat, pig, and horse kidneys are smooth and unlobulated. The kidney has an outer cortex (containing glomeruli and proximal and distal tubules) and an inner medulla (containing the loops of Henle and collecting ducts). The renal pelvis collects urine from the medullary collecting ducts and drains into the ureter.

The nephron is the functional unit of the kidney. Each kidney contains approximately one million nephrons in mammals. A nephron consists of: the Bowman's capsule enclosing the glomerulus (a tuft of capillaries), the proximal convoluted tubule, the loop of Henle (descending and ascending limbs passing into the medulla), the distal convoluted tubule, and the collecting duct. The glomerulus and Bowman's capsule together form the renal corpuscle, the site of filtration. Collecting ducts from many nephrons converge into the renal pelvis.

Fill in the blank: The _____ is the functional unit of the kidney; each consists of a glomerulus within a Bowman's capsule, a proximal tubule, a loop of Henle, a distal tubule, and a collecting duct.

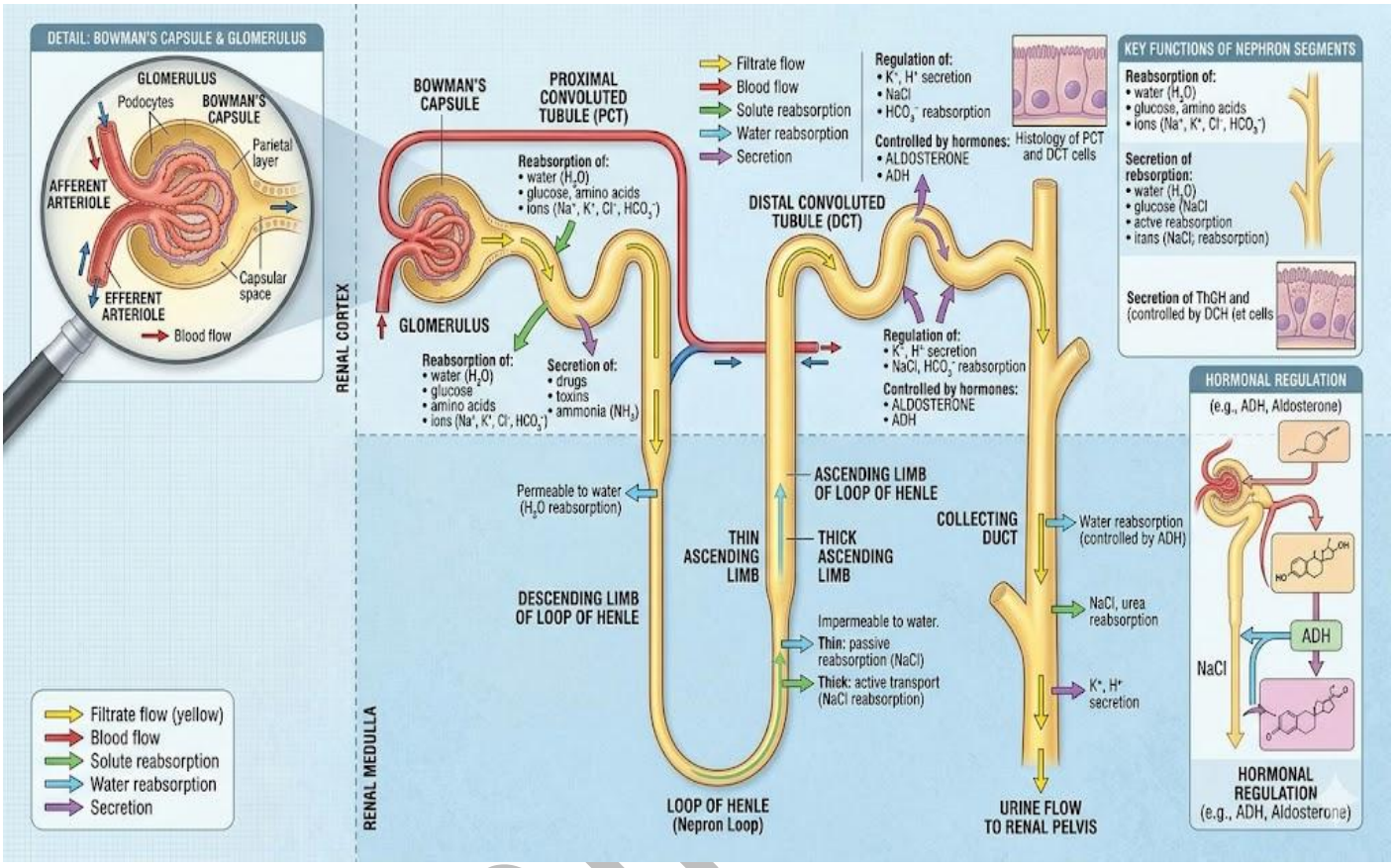

Figure 4.6: Diagram of a nephron showing all its structural components

4.3.2 Urine formation

Urine is formed by three processes. Glomerular filtration: blood pressure in the glomerular capillaries forces water, small solutes (glucose, urea, amino acids, electrolytes, creatinine), and small proteins across the filtration membrane into Bowman's capsule, forming the glomerular filtrate. Large proteins and blood cells are retained. Filtration rate in cattle is approximately 300 to 400 ml per minute. Tubular reabsorption: as the filtrate passes through the proximal tubule, loop of Henle, and distal tubule, over 99 per cent of the filtered water and virtually all the glucose and amino acids are actively reabsorbed into the peritubular capillaries.

Tubular secretion: additional waste substances (hydrogen ions, potassium, certain drugs and toxins) are actively transported from the peritubular blood into the tubular fluid, adding to the waste in the forming urine. The final concentrated urine drains from the collecting ducts into the renal pelvis. Antidiuretic hormone (ADH), produced by the hypothalamus and released from the

posterior pituitary, increases water reabsorption in the collecting ducts during dehydration, concentrating the urine. Aldosterone from the adrenal cortex promotes sodium reabsorption in the distal tubule, conserving electrolytes.

Fill in the blank: Antidiuretic hormone (ADH) increases water _____ in the collecting ducts of the kidney, concentrating the urine and conserving body water during dehydration.

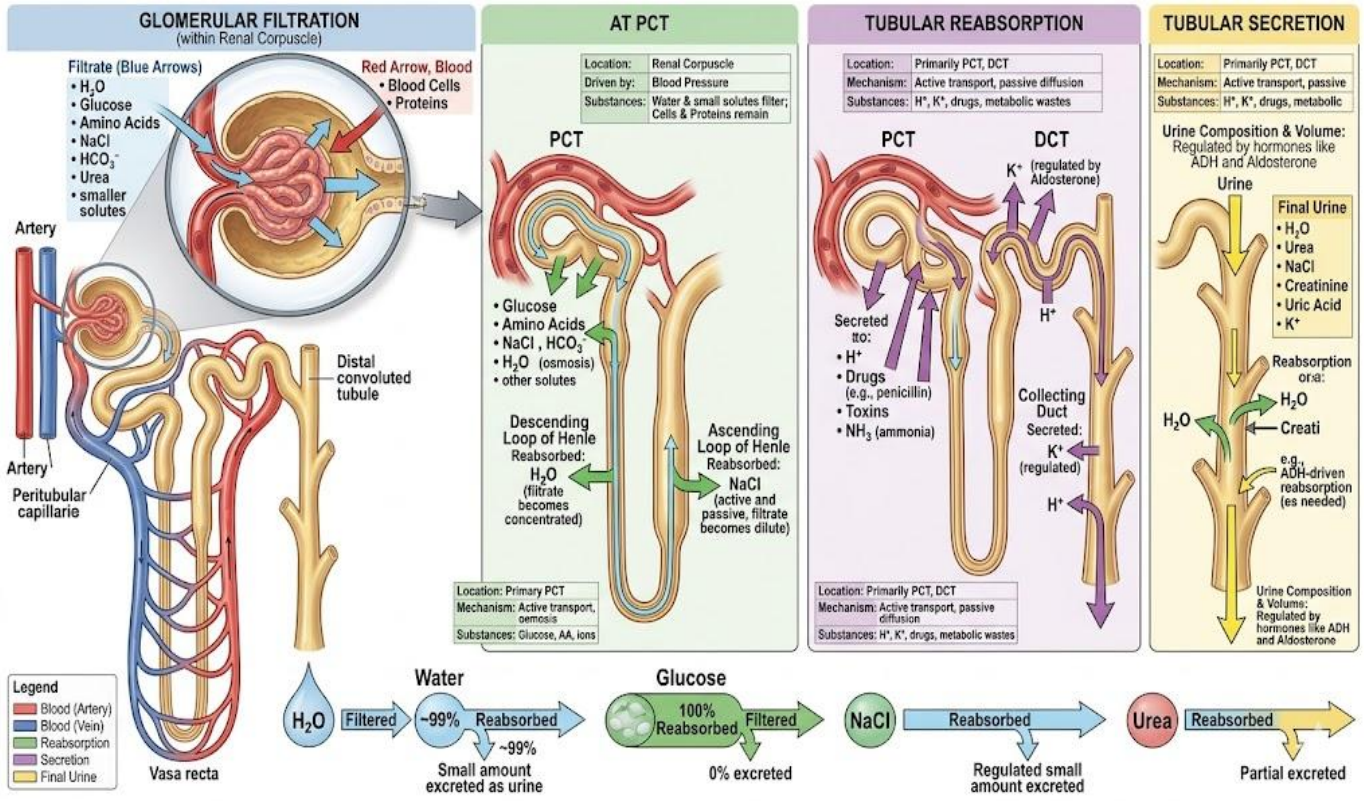

Figure 4.7: Diagram showing the three processes of urine formation along the nephron

4.3.3 The ureters, urinary bladder, and urethra

Urine produced by the kidneys drains via the ureters (one per kidney) to the urinary bladder for storage. The ureters are muscular tubes whose peristaltic contractions move urine from renal pelvis to bladder. The urinary bladder is a distensible muscular sac lined by transitional epithelium (urothelium) that can stretch to accommodate large volumes; it is connected to the urethra at its neck. In cattle the bladder capacity is approximately one to two litres.

The urethra carries urine from the bladder to the exterior. In females the urethra is short and opens into the vestibule of the vulva. In males the urethra is much longer, passing through the prostate gland and penis; it serves as a common passage for urine and semen. Urinary tract infections (cystitis, pyelonephritis) are common in cattle, particularly in females due to the short urethra. Urolithiasis (bladder stones) is an important condition in feedlot steers, wethers, and male goats, where urinary calculi block the sigmoid flexure or urethral process.

Fill in the blank: _____ is the formation of urinary calculi (stones) that can block the urethra of male ruminants at the sigmoid flexure or urethral process, causing a life-threatening urinary obstruction.

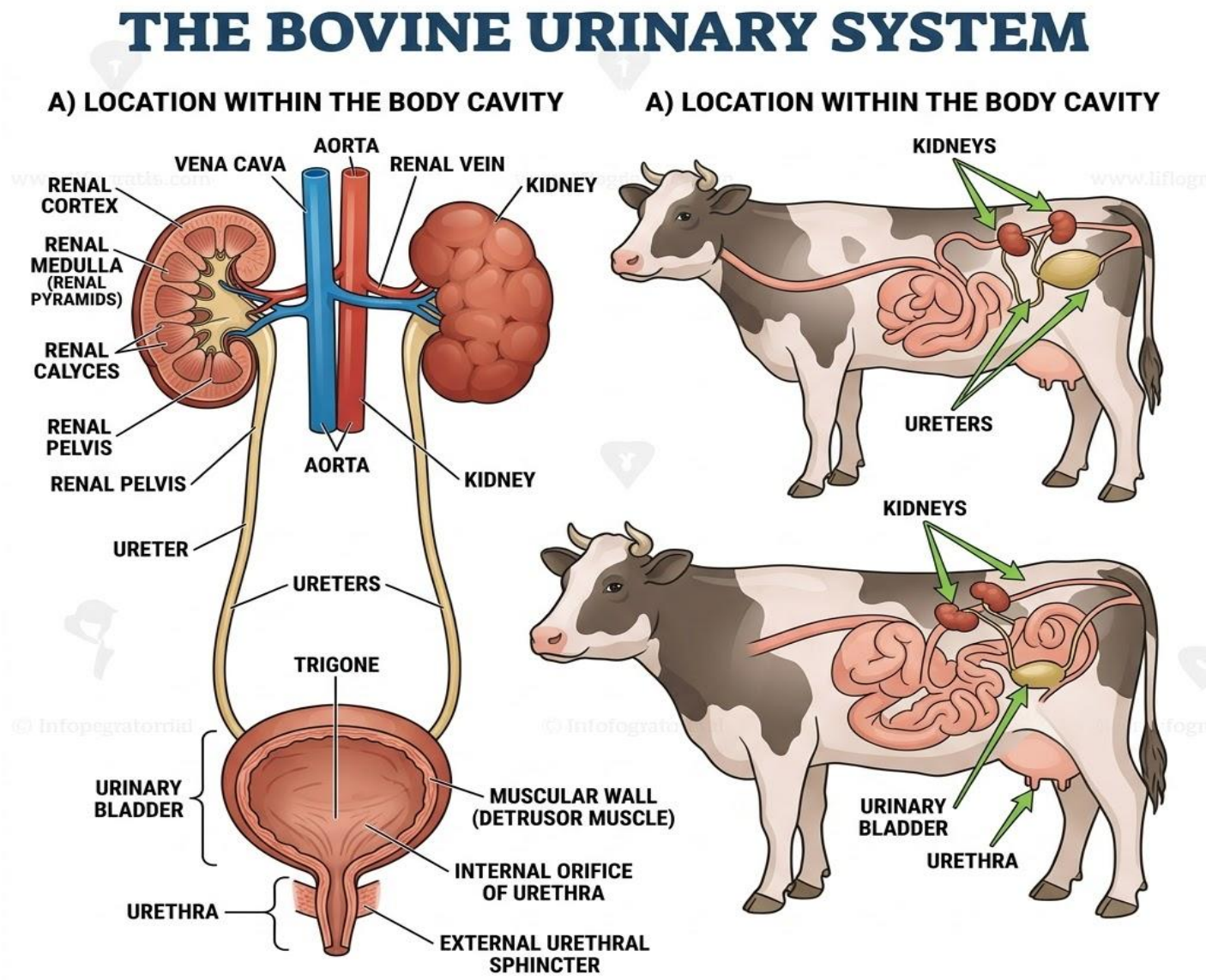

Figure 4.8: Diagram of the urinary system of a cow showing kidneys, ureters, bladder, and urethra

Pilot questions 4.3

1. Describe the gross structure of the mammalian kidney naming the major regions.
2. Name the structural components of a nephron from filtration to drainage.
3. Explain the three processes of urine formation.
4. Explain how ADH regulates urine concentration.

5. Describe urolithiasis in male ruminants and explain why it is life-threatening.

4.4 The Nervous System

4.4.1 Organisation of the nervous system

The nervous system is divided into the central nervous system (CNS, consisting of the brain and spinal cord) and the peripheral nervous system (PNS, consisting of all the nerves outside the CNS). The brain is the control centre, receiving sensory information, integrating it, and generating motor commands. The spinal cord transmits signals between the brain and the body and mediates reflex arcs. The PNS is further divided into the somatic nervous system (voluntary control of skeletal muscle) and the autonomic nervous system (involuntary control of smooth muscle, cardiac muscle, and glands).

The brain consists of the cerebrum (highest cognitive functions, voluntary movement, sensory processing), cerebellum (coordination, balance, and fine motor control), brainstem (medulla oblongata, pons, and midbrain controlling heart rate, respiration, blood pressure, and basic reflexes), and diencephalon (thalamus relaying sensory information; hypothalamus regulating homeostasis including temperature, thirst, hunger, and endocrine function). Twelve pairs of cranial nerves arise from the brain; 31 to 36 pairs of spinal nerves arise from the spinal cord, varying by species.

Fill in the blank: The _____ controls coordination and balance; damage to it causes ataxia and incoordination in farm animals.

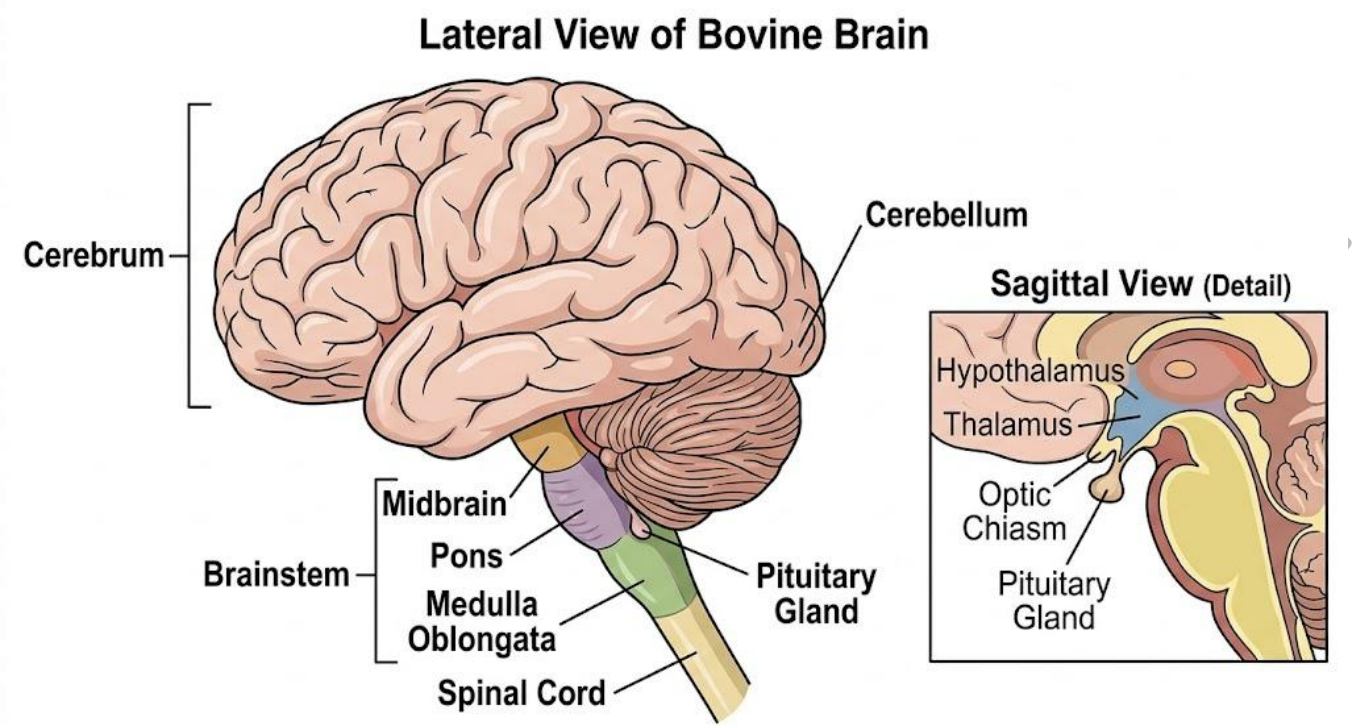

Figure 4.9: Diagram of the bovine brain showing major regions and their functions

4.4.2 The neuron and nerve impulse

The neuron is the structural and functional unit of the nervous system. A typical motor neuron consists of the cell body (soma, containing the nucleus), multiple dendrites (short processes that receive incoming signals), and a single axon (a long process that conducts impulses away from the cell body to effector organs or other neurons). The axon is often covered by a myelin sheath produced by Schwann cells; myelination dramatically increases impulse conduction velocity. A nerve is a bundle of axons bound together by connective tissue.

A nerve impulse is an action potential: a rapid, self-propagating reversal of electrical charge across the axon membrane caused by the sequential opening of sodium (Na^+) and potassium (K^+) ion channels. At rest, the inside of the axon is negative (resting membrane potential approximately -70 mV). Stimulation causes Na^+ to rush in (depolarisation), reversing the charge; then K^+ flows out (repolarisation), restoring the resting potential. The action potential travels along the axon; in myelinated axons it jumps between the nodes of Ranvier (saltatory conduction), reaching speeds of up to 120 metres per second.

Fill in the blank: In myelinated axons, the action potential jumps between the nodes of _____ in a process called saltatory conduction, greatly increasing impulse speed.

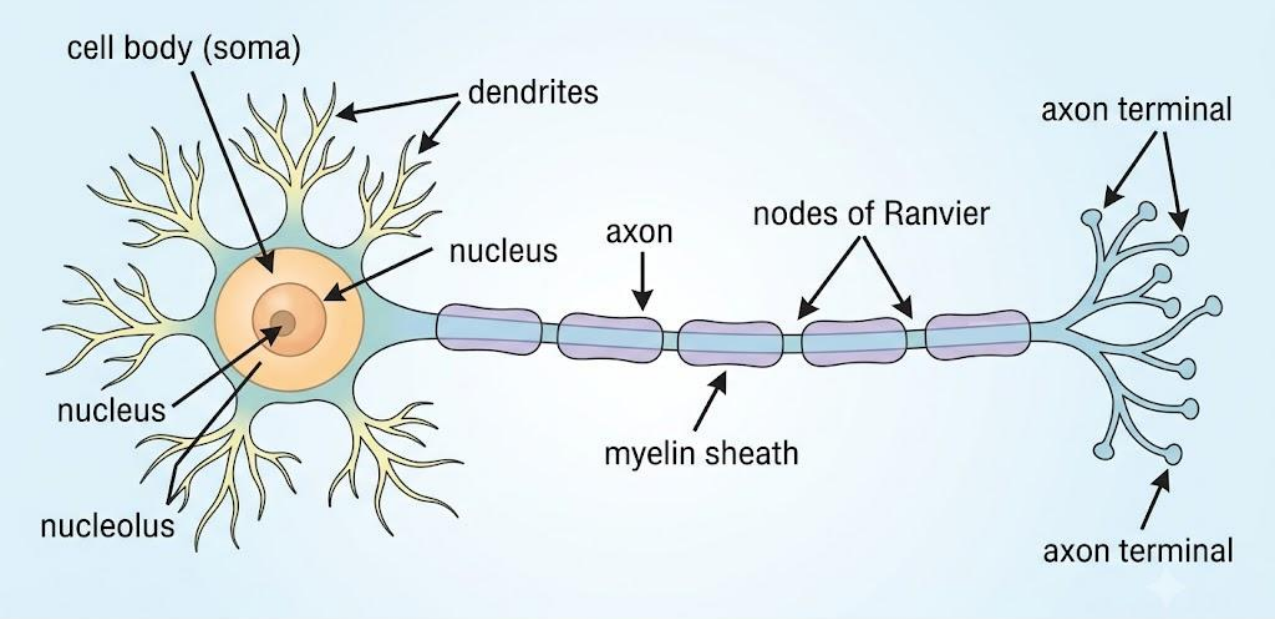

Figure 4.10: Diagram of a motor neuron showing dendrites, cell body, axon, myelin sheath, and nodes of Ranvier

4.4.3 The autonomic nervous system

The autonomic nervous system (ANS) regulates the internal environment of the body without conscious control. It is divided into the sympathetic nervous system (fight-or-flight response: increases heart rate, dilates airways, mobilises glucose, diverts blood to muscles) and the parasympathetic nervous system (rest-and-digest: decreases heart rate, stimulates digestion, conserves energy). Most organs receive both sympathetic and parasympathetic innervation and their function represents the balance between the two.

In farm animal production, the ANS has several critical applications. Stress activates the sympathetic system, releasing cortisol and adrenaline (epinephrine), which suppress immune function and reduce production performance (milk let-down inhibition, reduced feed intake, impaired reproduction). Milk ejection requires the release of oxytocin from the posterior

pituitary in response to teat stimulation; stress (fear, pain, unfamiliar milkers) can block this reflex via sympathetic activation. Understanding the ANS guides stockmanship and low-stress handling practices that protect animal welfare and production efficiency.

Fill in the blank: Stress activates the _____ nervous system, releasing cortisol and adrenaline, which suppress immune function, inhibit milk let-down, and reduce overall production performance.

Organ/System	Sympathetic	Parasympathetic
Heart	Increases heart rate and contractility	Decreases heart rate
Lungs	Bronchodilation (airway relaxation)	Bronchoconstriction (airway narrowing)
Digestive tract	Decreases motility and secretions	Increases motility and secretions
Urinary bladder	Relaxes detrusor muscle, contracts sphincter (urine retention)	Contracts detrusor muscle, relaxes sphincter (urination)
Pupils	Dilation (mydriasis)	Constriction (miosis)
Salivary glands	Produces thick, viscous saliva	Produces watery, enzyme-rich saliva

Table 4.1: Comparison of sympathetic and parasympathetic effects on major organs

Pilot questions 4.4

1. Distinguish between the CNS and PNS and name the major divisions of each.
2. Name the four main regions of the brain and state the primary function of each.
3. Describe the structure of a motor neuron.
4. Explain what an action potential is and how it travels along a myelinated axon.
5. Explain the difference between the sympathetic and parasympathetic nervous systems and give one example of each in farm animal production.

Series Summary

This Series described four major regulatory and integrating systems. We began with the cardiovascular system, covering the four-chambered heart, its valves and cardiac cycle, the three

vessel types, the systemic and pulmonary circulations, and the composition and functions of blood. We then examined the lymphatic system, describing its three functions (fluid drainage, fat transport, immune defence), the structure of lymph nodes, the major lymphoid organs including the avian bursa of Fabricius, and the critical importance of colostrum for passive immunity in neonatal farm animals.

We then covered the urinary system, describing the lobulated bovine kidney, the nephron and its components, the three processes of urine formation (filtration, reabsorption, secretion), the hormonal regulation of water balance by ADH, and the clinical conditions of cystitis and urolithiasis. Finally, we described the nervous system, covering the CNS/PNS organisation, the major brain regions, the structure of the neuron and the mechanism of the action potential, and the autonomic nervous system with its implications for low-stress animal handling and production efficiency. By completing this Series, you should be able to achieve all nine Series Learning Outcomes (SLO 4.1 to SLO 4.9).

Glossary of Terms

- **Action potential:** a rapid, self-propagating reversal of electrical charge across the axon membrane caused by sequential opening of Na+ and K+ ion channels; the electrical signal of the nervous system.
- **ADH (antidiuretic hormone):** a hormone produced by the hypothalamus and released from the posterior pituitary that increases water reabsorption in the collecting ducts of the kidney.
- **Aldosterone:** a steroid hormone from the adrenal cortex that promotes sodium reabsorption in the distal tubule of the nephron, conserving body electrolytes.
- **Anaemia:** a reduction in circulating red blood cells or haemoglobin concentration; causes pale mucous membranes, weakness, and reduced production; common in heavily parasitised farm animals.
- **Atrium:** the receiving chamber of the heart (right atrium receives deoxygenated blood from the body; left atrium receives oxygenated blood from the lungs).

- **Autonomic nervous system (ANS):** the division of the PNS that controls smooth muscle, cardiac muscle, and glands involuntarily; divided into sympathetic (fight-or-flight) and parasympathetic (rest-and-digest) subdivisions.
- **Bowman's capsule:** the cup-shaped structure at the start of the nephron that surrounds the glomerulus and collects the glomerular filtrate.
- **Bursa of Fabricius:** a lymphoid organ unique to birds, located dorsal to the cloaca, where B lymphocytes mature; regresses at sexual maturity.
- **Cardiac cycle:** the sequence of events in one heartbeat, consisting of systole (ventricular contraction and ejection) and diastole (ventricular relaxation and filling).
- **Colostrum:** the first milk produced after parturition, rich in immunoglobulins (IgG, IgA, IgM) that provide passive immunity to the neonate; must be consumed within 24 to 36 hours of birth for effective antibody absorption.
- **Dendrite:** a short branching process of a neuron that receives incoming signals from other neurons or sensory receptors.
- **Glomerular filtration:** the first step in urine formation; blood pressure forces water and small solutes from glomerular capillaries into Bowman's capsule to form the glomerular filtrate.
- **Glomerulus:** a tuft of capillaries within Bowman's capsule; the site of glomerular filtration in the nephron.
- **Haemoglobin:** the iron-containing protein in red blood cells that binds and transports oxygen from the lungs to tissues and assists carbon dioxide transport.
- **Loop of Henle:** the U-shaped portion of the nephron tubule that descends into the medulla; creates the osmotic gradient that enables urine concentration.
- **Lymph:** fluid derived from blood plasma that accumulates in interstitial spaces; collected by lymphatic capillaries and transported through the lymphatic system.
- **Lymph node:** a small bean-shaped organ along lymphatic vessels where lymph is filtered and immune responses are initiated; enlarged in infection.
- **Myelin sheath:** a lipid-rich insulating layer around nerve axons produced by Schwann cells; increases impulse conduction velocity and is the basis of saltatory conduction.

- **Nephron:** the functional unit of the kidney; comprises the Bowman's capsule, glomerulus, proximal tubule, loop of Henle, distal tubule, and collecting duct.
- **Nodes of Ranvier:** gaps in the myelin sheath of myelinated axons where the action potential is regenerated; the basis of saltatory conduction.
- **Oedema:** abnormal accumulation of fluid in the interstitial spaces, often caused by impaired lymphatic drainage, reduced plasma protein, or increased capillary permeability.
- **Parasympathetic nervous system:** the rest-and-digest division of the ANS; decreases heart rate, stimulates digestion, and conserves energy.
- **Passive immunity:** immunity conferred by transfer of pre-formed antibodies from dam to neonate via colostrum; protects the neonate until active immunity develops.
- **Peristalsis:** coordinated waves of smooth muscle contraction that propel contents along hollow tubes, including the ureters.
- **Portal circulation:** the vascular pathway by which nutrient-rich blood from the gastrointestinal tract and spleen drains via the portal vein to the liver before entering the systemic circulation.
- **Renal cortex:** the outer region of the kidney containing the glomeruli and proximal and distal convoluted tubules.
- **Renal medulla:** the inner region of the kidney containing the loops of Henle and collecting ducts.
- **Saltatory conduction:** the propagation of an action potential in myelinated axons by jumping between nodes of Ranvier, greatly increasing conduction velocity.
- **Spleen:** the largest lymphoid organ; filters blood, removes aged red blood cells, and mounts immune responses to blood-borne antigens.
- **Sympathetic nervous system:** the fight-or-flight division of the ANS; increases heart rate, dilates airways, mobilises glucose, and diverts blood to muscles.
- **Tubular reabsorption:** the transport of substances (glucose, water, amino acids, electrolytes) from the tubular filtrate back into the peritubular blood; recovers over 99 per cent of filtered water.
- **Tubular secretion:** the active transport of additional waste substances (H+, K+, drugs) from peritubular blood into the tubular fluid.

- **Urolithiasis:** the formation of mineral deposits (calculi, stones) in the urinary tract; life-threatening in male ruminants when calculi block the urethra.
- **Ventricle:** the pumping chamber of the heart (right ventricle pumps to the lungs; left ventricle pumps to the body).

Concept Check Questions [Series 4]

Objective Questions

1. The left ventricular wall is thicker than the right because it must generate higher pressure to drive blood through the _____ circulation. (Linked to SLO 4.1)
2. All exchange of nutrients, gases, and waste between blood and tissues occurs across the walls of _____. (Linked to SLO 4.2)
3. The _____ of Fabricius is a lymphoid organ in birds where B lymphocytes mature. (Linked to SLO 4.5)
4. The functional unit of the kidney is called the _____. (Linked to SLO 4.6)
5. The _____ controls coordination and balance; damage causes ataxia in farm animals. (Linked to SLO 4.8)

Short-Answer Questions

1. Describe the path of blood through the heart from the right atrium to the aorta. (Linked to SLO 4.1)
2. State three functions of blood. (Linked to SLO 4.3)
3. Explain passive immunity and state why colostrum must be consumed within 24 to 36 hours of birth. (Linked to SLO 4.5)
4. Explain the three processes of urine formation. (Linked to SLO 4.7)
5. Compare the sympathetic and parasympathetic nervous systems and give one production example of each. (Linked to SLO 4.9)

Long-Answer Questions

1. Describe the cardiovascular system of farm animals, explaining the structure of the heart and cardiac cycle, the differences between arteries, capillaries, and veins, the systemic and pulmonary circulations, and the composition and functions of blood. (Linked to SLOs 4.1, 4.2, 4.3)
2. Describe the urinary system of farm animals, explaining the structure of the kidney and nephron, the three processes of urine formation, the role of ADH and aldosterone in regulating urine concentration, and the clinical significance of urolithiasis in male ruminants. (Linked to SLOs 4.6, 4.7)
3. Evaluate the nervous system of farm animals, describing CNS and PNS organisation, the structure of the neuron and mechanism of the action potential, and the role of the autonomic nervous system in farm animal production and welfare. (Linked to SLOs 4.8, 4.9)

Answers to Concept Check Questions [Series 4]

Objective Questions

1. Systemic.
2. Capillaries.
3. Bursa.
4. Nephron.
5. Cerebellum.

Short-Answer Questions

1. Deoxygenated blood enters the right atrium via the venae cavae, passes through the tricuspid valve into the right ventricle, is ejected through the pulmonary valve into the pulmonary artery to the lungs, returns oxygenated to the left atrium via pulmonary veins, passes through the mitral valve into the left ventricle, and is ejected through the aortic valve into the aorta.
2. Transport: carries oxygen (via haemoglobin), nutrients, hormones, and waste products to and from every cell. Regulation: maintains body temperature through heat distribution, pH via buffer systems, and osmotic pressure via plasma proteins. Protection: leucocytes and antibodies defend against infection; platelets and clotting factors achieve haemostasis when vessels are damaged.

3. Passive immunity is immunity conferred by pre-formed antibodies from the dam transferred to the neonate via colostrum. The neonate lacks functional B and T lymphocytes and is unable to mount its own immune response at birth. Colostral IgG, IgA, and IgM are absorbed intact across the intestinal epithelium for the first 24 to 36 hours; after gut closure, the epithelium no longer absorbs intact proteins and the window for passive transfer is permanently closed.
4. Glomerular filtration: blood pressure forces water, small solutes, and urea from glomerular capillaries into Bowman's capsule; large proteins and blood cells are retained. Tubular reabsorption: over 99 per cent of filtered water and all glucose and amino acids are actively reabsorbed from the tubular filtrate back into the peritubular blood as it passes through the proximal tubule, loop of Henle, and distal tubule. Tubular secretion: additional waste (H+, K+, drugs) is actively transported from peritubular blood into the tubular fluid to be excreted in urine.
5. Sympathetic (fight-or-flight): activates during stress or exercise; increases heart rate, dilates airways, mobilises glucose, diverts blood to muscles; production example: stress during milking activates sympathetic system, releasing adrenaline that blocks oxytocin action and inhibits milk let-down. Parasympathetic (rest-and-digest): active during calm states; decreases heart rate, stimulates gut motility and secretion, conserves energy; production example: resting cattle with full parasympathetic activity have optimal rumen motility and digestion, maximising feed conversion efficiency.

Long-Answer Questions

1. Heart: four chambers (right atrium and ventricle receive and pump deoxygenated blood to lungs; left atrium and ventricle receive oxygenated blood and pump to body); four valves (tricuspid, mitral, pulmonary, aortic prevent backflow); cardiac cycle (systole/ejection, diastole/filling); heart rate 60 to 80 bpm cattle, 250 to 350 bpm chicken. Vessels: arteries (thick muscular wall, high pressure); capillaries (one cell thick, all gas/nutrient exchange); veins (thin wall, valves, low pressure). Circulations: systemic (left heart to body via aorta and back via venae cavae), pulmonary (right heart to lungs via pulmonary artery and back via pulmonary veins), portal (GI tract to liver). Blood: plasma (water, albumin, globulins, fibrinogen, nutrients, hormones); erythrocytes (haemoglobin, O2 and CO2 transport); leucocytes (immune defence); platelets (clotting). Functions: transport, regulation, protection.

2. Kidney structure: paired retroperitoneal organs; bovine kidneys lobulated; cortex (glomeruli, proximal and distal tubules) and medulla (loops of Henle, collecting ducts); renal pelvis to ureter. Nephron: Bowman's capsule + glomerulus (renal corpuscle), proximal tubule, loop of Henle, distal tubule, collecting duct; approximately one million nephrons per kidney. Urine formation: filtration (blood pressure drives filtrate into Bowman's capsule); reabsorption (over 99% of water, all glucose and amino acids returned to blood in tubules); secretion (H+, K+, drugs added to tubular fluid). Hormonal regulation: ADH increases water reabsorption in collecting duct (concentrated urine in dehydration); aldosterone promotes Na+ reabsorption in distal tubule. Urolithiasis: mineral calculi block urethra of male ruminants at sigmoid flexure or urethral process; urine backs up causing bladder rupture; fatal if not treated; high concentrate/low roughage diets and Ca:P imbalance predispose.
3. CNS: brain and spinal cord; brain regions: cerebrum (cognition, voluntary movement), cerebellum (coordination, balance), brainstem (heart rate, respiration, blood pressure), hypothalamus (homeostasis, endocrine coordination). PNS: somatic (voluntary skeletal muscle control) and autonomic (involuntary smooth muscle, cardiac muscle, glands). Neuron: cell body, dendrites (receive signals), axon (transmit signals), myelin sheath (Schwann cells, increases speed), nodes of Ranvier (saltatory conduction, up to 120 m/s). Action potential: resting -70 mV; Na+ influx causes depolarisation; K+ efflux causes repolarisation; self-propagating along axon. ANS: sympathetic (fight-or-flight, heart rate increase, airway dilation, glucose mobilisation; stress inhibits milk ejection and immune function; production loss); parasympathetic (rest-and-digest, heart rate decrease, gut stimulation, energy conservation; calm handling optimises rumination, digestion, and reproduction). Low-stress handling based on ANS physiology is the practical application.

Answers to Pilot Questions [Series 4]

Part 4.1: The Cardiovascular System

1. Right atrium (receives deoxygenated blood from body via venae cavae), through tricuspid valve into right ventricle (pumps to lungs via pulmonary artery), oxygenated blood returns to left atrium via pulmonary veins, through mitral valve into left ventricle (pumps to body via aorta). Atria receive; ventricles pump. Interventricular septum separates the two sides. Left wall is thicker because it generates systemic pressure.

2. Tricuspid valve (between right atrium and ventricle, prevents backflow to atrium during systole); mitral (bicuspid) valve (between left atrium and ventricle, same function on left side); pulmonary semilunar valve (at the entrance to the pulmonary artery, prevents backflow from artery into right ventricle); aortic semilunar valve (at the entrance to the aorta, prevents backflow from aorta into left ventricle).
3. Arteries: thick muscular and elastic walls; carry blood away from the heart under high pressure; no valves (except semilunar at origin). Capillaries: one cell thick (endothelium only); smallest vessels; all nutrient, gas, and waste exchange occurs here. Veins: thin walls; carry blood back to the heart under low pressure; contain valves that prevent backflow; receive blood from capillaries via venules.
4. The portal circulation carries nutrient-rich blood absorbed from the gastrointestinal tract (stomach, small intestine, large intestine) and from the spleen through the portal vein directly to the liver before it enters the systemic circulation. Its significance for nutrition: the liver receives the full load of absorbed glucose, amino acids, VFAs, and other nutrients first, allowing it to regulate nutrient distribution (storing glucose as glycogen, converting excess amino acids, processing VFAs), protecting the rest of the body from sudden large fluctuations in circulating nutrient concentrations.
5. Transport: carries oxygen to every metabolising cell (measured as oxygen delivery = cardiac output x haemoglobin saturation), linking directly to growth rate and milk production; reduced O2 delivery from anaemia causes loss of production. Regulation: maintains core body temperature by redistributing blood (vasodilation in heat; vasoconstriction in cold), which is relevant to thermal comfort management of housed animals. Protection: neutrophils and macrophages in blood are the first mobile defenders against bacterial infections; adequate immune cell numbers depend on good nutrition and absence of chronic stress.

Part 4.2: The Lymphatic System

1. Drainage of excess interstitial fluid back to the blood (preventing oedema); transport of dietary fat and fat-soluble vitamins from the intestinal lacteals to the systemic circulation via the thoracic duct; immune surveillance and defence through lymph nodes and lymphoid organs.
2. Lymph has no pump equivalent to the heart. It moves through lymphatic vessels by three mechanisms: compression of lymphatic vessels by surrounding skeletal muscle contractions

during normal movement and exercise; pressure changes from respiratory movements (inspiration creates a pressure gradient that draws lymph towards the thorax); and the presence of one-way valves in lymphatic vessel walls that prevent backflow and ensure unidirectional movement toward the thoracic duct.

3. A lymph node is enclosed in a fibrous capsule with trabeculae extending into the interior. Afferent lymphatic vessels enter around the periphery. The cortex contains B lymphocyte follicles (primary follicles and secondary germinal centres after antigen stimulation). The paracortex contains T lymphocytes. The medulla contains macrophages and plasma cells. Efferent lymphatic vessels leave at the hilum. Lymph percolates through these zones where pathogens are filtered out, antigens are presented to lymphocytes, and immune responses are initiated.
4. Spleen: filters blood, removes aged and damaged red blood cells, stores platelets, and mounts immune responses to blood-borne antigens. Thymus: site of T lymphocyte maturation and education; most active in neonates and young animals; involutes at puberty. Peyer's patches: clusters of lymphoid follicles in the intestinal wall that monitor gut contents for antigens and initiate mucosal immune responses. Bursa of Fabricius (birds only): site of B lymphocyte maturation; dorsal to the cloaca; regresses at sexual maturity.
5. Passive immunity is immunity derived from antibodies produced by the dam and transferred to the neonate rather than from the neonate's own immune response. Colostrum must be consumed within 24 to 36 hours of birth because the neonatal intestinal epithelium is initially permeable to intact immunoglobulin molecules (pinocytosis); after gut closure (approximately 24 to 36 hours post-partum), the epithelial cells develop tight junctions and mature enzymes that digest immunoglobulins, preventing their absorption; antibodies consumed after gut closure are digested rather than absorbed.

Part 4.3: The Urinary System

1. The kidney has a bean-shaped outer surface (lobulated in cattle, smooth in sheep, pigs, and horses) and an indentation called the hilus where vessels, nerves, and the ureter enter and leave. Internally: the cortex (outer zone, dark red, containing glomeruli and proximal and distal convoluted tubules), the medulla (inner zone, paler, containing loops of Henle and collecting ducts organised into renal pyramids), and the renal pelvis (funnel-shaped central space collecting urine from the collecting ducts and draining into the ureter).

2. From filtration to drainage: glomerulus (tuft of capillaries) within Bowman's capsule (forms the filtrate); proximal convoluted tubule (major site of reabsorption); descending loop of Henle (water reabsorption); ascending loop of Henle (salt reabsorption, impermeable to water); distal convoluted tubule (fine-tuning of electrolyte balance under aldosterone control); collecting duct (water reabsorption under ADH control); renal pelvis (collects urine); ureter (conducts urine to bladder).
3. Glomerular filtration: hydrostatic pressure in the glomerular capillaries (approximately 60 mmHg) forces water, urea, creatinine, glucose, amino acids, and electrolytes through the filtration membrane into Bowman's capsule; proteins and blood cells are too large to pass. Tubular reabsorption: the filtrate passes through the tubules where over 99 per cent of water and all glucose and amino acids are actively or passively transported back into the peritubular capillaries. Tubular secretion: the tubular cells actively transport additional waste substances (H^+, K^+, creatinine, drugs, and toxins) from the peritubular blood into the tubular fluid.
4. When blood osmolarity rises (dehydration) or blood volume falls, osmoreceptors in the hypothalamus detect the change and signal the posterior pituitary to release ADH into the blood. ADH binds to receptors on collecting duct cells and stimulates the insertion of aquaporin (water channel) proteins into the cell membrane. This dramatically increases the permeability of the collecting duct to water, allowing water to be reabsorbed from the dilute tubular fluid into the hypertonic medullary interstitium, concentrating the urine and conserving body water.
5. Urolithiasis is the formation of mineral calculi (stones) in the urinary tract of male ruminants. Calculi (commonly struvite or calcium oxalate) form in the bladder and pass into the urethra, where they lodge at anatomical narrowings: the sigmoid flexure (the S-bend in the bull's penis) or the urethral process (the worm extension at the end of the penis in small ruminants). The obstruction prevents urine outflow; urine backs up causing bladder distension and, if untreated, bladder rupture leading to uroperitoneum (urine in the peritoneal cavity), septic peritonitis, and death. It is life-threatening because male ruminants cannot pass urine around the obstruction.

Part 4.4: The Nervous System

1. CNS: brain and spinal cord; the brain integrates information and generates commands; the spinal cord transmits signals between brain and body and mediates reflex arcs. CNS is

protected by the skull and vertebral column, and by the meninges and cerebrospinal fluid. PNS: all nerves outside the CNS; divided into somatic (voluntary, controls skeletal muscle via motor neurons) and autonomic (involuntary, controls smooth muscle, cardiac muscle, and glands); autonomic further divided into sympathetic and parasympathetic.

2. Cerebrum: largest region; responsible for voluntary movement, sensory perception, learning, memory, and behaviour. Cerebellum: coordinates voluntary movement, maintains balance and posture, refines motor commands; damage causes ataxia. Brainstem (medulla oblongata, pons, midbrain): regulates vital functions (heart rate, respiratory rate, blood pressure, swallowing); site of origin of most cranial nerves. Hypothalamus: regulates homeostasis (temperature, thirst, hunger, sleep); controls the endocrine system via the pituitary gland.
3. A motor neuron has: a cell body (soma) containing the nucleus and organelles; dendrites (multiple short branching processes receiving incoming signals from other neurons); an axon hillock (where the axon arises from the cell body; the site where action potentials are initiated); an axon (a long single process conducting impulses away from the cell body to effector organs); a myelin sheath (lipid-rich insulation produced by Schwann cells, interrupted at regular intervals by nodes of Ranvier); and axon terminals (synaptic boutons that release neurotransmitters at synapses).
4. At rest, the axon membrane maintains a resting potential of approximately -70 mV (inside negative). A stimulus raises the membrane potential to the threshold (-55 mV), causing voltage-gated Na+ channels to open; Na+ rushes in (depolarisation), reversing the potential to approximately +35 mV. Voltage-gated K+ channels then open; K+ flows out (repolarisation), restoring the resting potential. This cycle of depolarisation and repolarisation constitutes one action potential, which is self-propagating along the axon. In myelinated axons, the depolarisation jumps between nodes of Ranvier (saltatory conduction), reaching speeds up to 120 m/s.
5. Sympathetic: fight-or-flight; increases heart rate, dilates pupils, dilates airways, mobilises glucose, increases blood flow to muscles; relevant production example: transport and handling stress activates sympathetic system, releasing cortisol and adrenaline, which suppress immune function and increase disease susceptibility; in dairy cows, fear activates sympathetic system and adrenaline blocks oxytocin receptors, inhibiting milk let-down reflex and reducing milk yield. Parasympathetic: rest-and-digest; decreases heart rate, stimulates salivation and gut motility, promotes digestion; production example: calm dairy cows in familiar environments with low stress activate the parasympathetic system, optimising rumen motility and feed conversion, maximising milk production.

References and Attributions [Series 4]

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Figures, Plates, Tables, and Boxes

- Figure 4.1: Heart chambers and valves Attribution: AI generated. Suggested OER search string: "heart chambers valves aorta frontal section labelled diagram OER".
- Figure 4.2: Double circulation diagram Attribution: AI generated. Suggested OER search string: "double circulation systemic pulmonary heart diagram OER".
- Figure 4.3: Blood components diagram Attribution: AI generated. Suggested OER search string: "blood components plasma erythrocytes leucocytes platelets functions OER".
- Figure 4.4: Lymphatic system diagram Attribution: AI generated. Suggested OER search string: "lymphatic system vessels lymph nodes thoracic duct farm animal OER".
- Figure 4.5: Lymph node cross-section Attribution: AI generated. Suggested OER search string: "lymph node cross-section cortex paracortex medulla afferent efferent OER".
- Box 4.1: Colostrum management rules Attribution: AI generated. Suggested OER search string: "colostrum management passive immunity newborn farm animals OER box".
- Figure 4.6: Nephron structure Attribution: AI generated. Suggested OER search string: "nephron structure labelled Bowmans capsule glomerulus loop Henle OER".
- Figure 4.7: Urine formation processes Attribution: AI generated. Suggested OER search string: "urine formation nephron filtration reabsorption secretion diagram OER".

- Figure 4.8: Bovine urinary system Attribution: AI generated. Suggested OER search string: "bovine urinary system kidneys ureters bladder urethra OER diagram".
- Figure 4.9: Bovine brain regions Attribution: AI generated. Suggested OER search string: "bovine brain regions labelled lateral view cerebrum cerebellum brainstem OER".
- Figure 4.10: Motor neuron structure Attribution: AI generated. Suggested OER search string: "motor neuron structure labelled axon myelin sheath nodes Ranvier OER".
- Table 4.1: Sympathetic vs parasympathetic effects Attribution: AI generated. Suggested OER search string: "sympathetic parasympathetic effects organs comparison table OER".

Course code: AGE 204

Course title: Anatomy and Physiology of Farm Animals

Course credit load: 2 Units

Series 5: Sensory Organs, Integumentary Structures, and External Features

- **Part 5.1: The Eye**
  - Sub Part 5.1.1: Structure of the mammalian eye
  - Sub Part 5.1.2: The avian eye and adaptations
  - Sub Part 5.1.3: Common eye conditions in farm animals
- **Part 5.2: The Ear**
  - Sub Part 5.2.1: Structure of the mammalian ear
  - Sub Part 5.2.2: The avian ear
  - Sub Part 5.2.3: Common ear conditions in farm animals
- **Part 5.3: The Integumentary System**
  - Sub Part 5.3.1: Structure and functions of the skin
  - Sub Part 5.3.2: Hair, wool, and feathers
  - Sub Part 5.3.3: Hooves, claws, and horns
- **Part 5.4: External Features and Body Condition**
  - Sub Part 5.4.1: External features and species identification
  - Sub Part 5.4.2: Body condition scoring
  - Sub Part 5.4.3: External signs of health and disease

Introduction

The sensory organs allow farm animals to perceive their environment, and the integumentary system forms the boundary between the animal and that environment. The eye and ear are the primary distance senses guiding behaviour, social interaction, and predator detection. The skin, hair, wool, feathers, hooves, and horns protect the body, regulate temperature, and produce important agricultural products. Understanding the structure and function of these external systems supports health monitoring, welfare assessment, and production management.

The aim of this Series is to describe the anatomy of the mammalian and avian eye and ear, cover common clinical conditions of these organs, describe the structure and functions of the integumentary system including skin, hair, wool, feathers, and keratinised structures, and explain how external features and body condition scoring are used in practical farm animal management. This final Series completes the whole-body approach to farm animal anatomy and physiology established throughout the course.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 5.1** describe the structure of the mammalian eye and explain how it forms an image (Linked to Part 5.1),
- **SLO 5.2** describe the distinctive features of the avian eye and explain how it differs from the mammalian eye (Linked to Part 5.1),
- **SLO 5.3** identify common eye and ear conditions affecting farm animals (Linked to Parts 5.1, 5.2),
- **SLO 5.4** describe the structure of the mammalian and avian ear and explain the mechanism of hearing (Linked to Part 5.2),
- **SLO 5.5** describe the structure and functions of the skin in mammals and birds (Linked to Part 5.3),
- **SLO 5.6** describe the structure of hair, wool, and feathers and explain their roles in production and thermoregulation (Linked to Part 5.3),

- **SLO 5.7** describe the structure of hooves, claws, and horns and explain their care and clinical significance (Linked to Part 5.3),
- **SLO 5.8** identify the key external features used to describe and distinguish farm animal species and breeds (Linked to Part 5.4), and
- **SLO 5.9** explain body condition scoring and describe the external signs used to assess animal health in the field (Linked to Part 5.4).

5.1 The Eye

5.1.1 Structure of the mammalian eye

The mammalian eye is a fluid-filled sphere enclosed in three layers. The outer fibrous layer consists of the sclera (white, tough outer coat that maintains eye shape) and the cornea (the transparent anterior portion through which light enters). The middle vascular layer (uvea) consists of the choroid (posterior layer rich in blood vessels that nourishes the retina), the ciliary body (produces aqueous humour and controls lens shape via the ciliary muscle and zonule fibres), and the iris (controls pupil diameter). The inner layer is the retina, which contains the photoreceptors.

Light passes through the cornea, aqueous humour, pupil, lens, and vitreous humour before striking the retina. The lens focuses the image on the retina by changing shape (accommodation). The retina contains two types of photoreceptors: rods (sensitive to low light levels, provide black-and-white vision) and cones (function in bright light, provide colour vision). The image is transmitted via the optic nerve to the visual cortex of the cerebrum. Farm animals such as cattle and sheep have horizontally elongated pupils providing a wide field of view for predator detection.

Fill in the blank: The retina contains _____ for low-light vision and cones for colour and bright-light vision; the image is transmitted to the brain via the optic nerve.

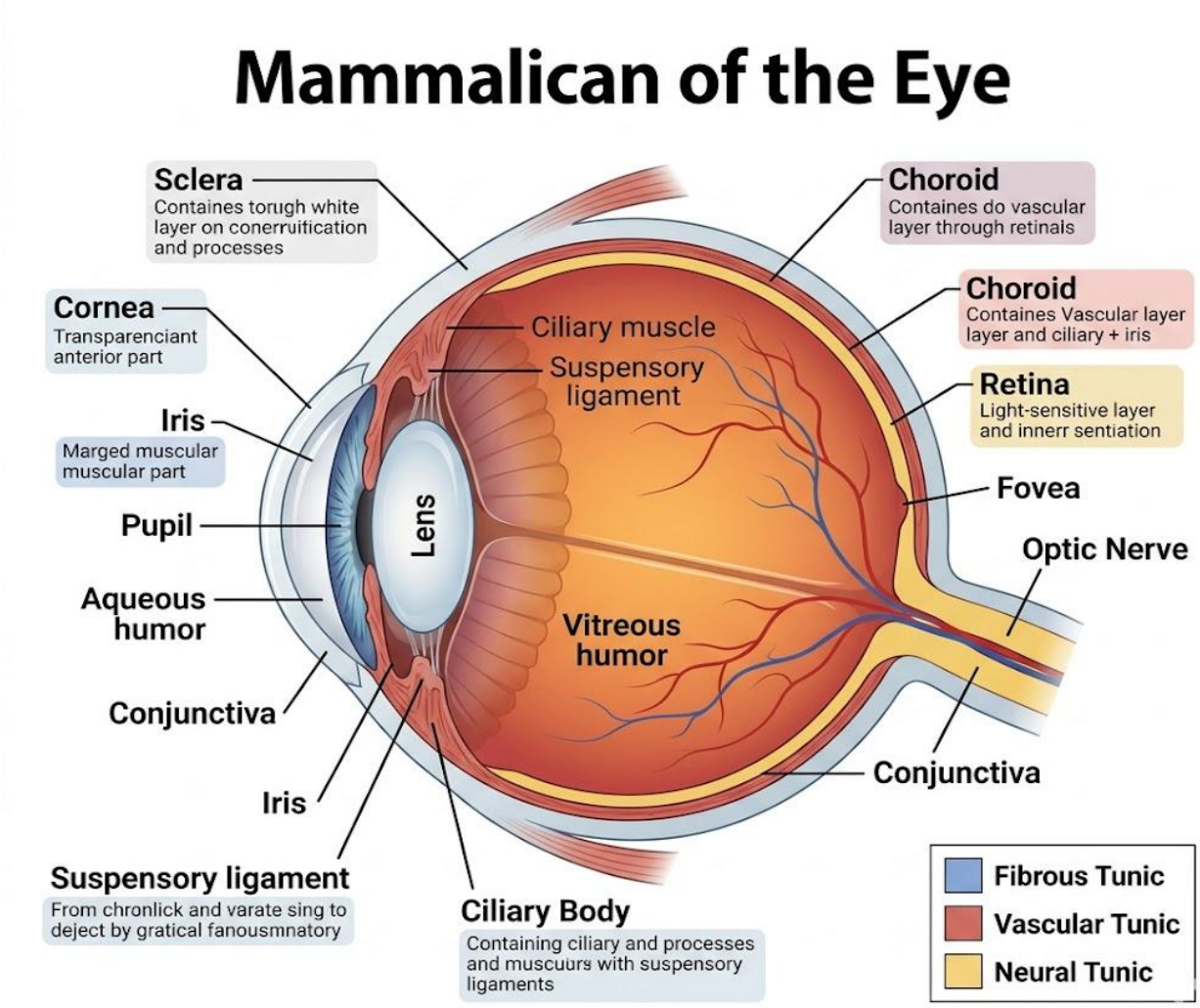

Figure 5.1: Cross-section diagram of the mammalian eye showing all structural layers

5.1.2 The avian eye and adaptations

The avian eye is proportionally much larger than the mammalian eye relative to body size, reflecting the importance of vision in birds. It is partially immobilised by a ring of small bones (sclerotic ossicles) in the sclera, so birds must move their whole head to redirect gaze rather than just rotating the eye. The pecten oculi is a unique vascular comb-like structure projecting from the optic disc into the vitreous; it nourishes the inner retina and may assist in detecting movement.

Birds have a higher density of photoreceptors than mammals, giving superior visual acuity. Many species have two foveas (areas of highest cone density) rather than the single mammalian fovea, providing two zones of sharp focus simultaneously. The avian eye contains a large proportion of cones, giving excellent colour vision including ultraviolet (UV) wavelengths. In poultry production, light management exploits avian photoreception: birds detect light directly via deep brain photoreceptors (not just the retina), which regulate reproductive cycles through the hypothalamic-pituitary axis.

Fill in the blank: The _____ oculi is a comb-like vascular structure unique to birds that projects from the optic disc into the vitreous humour and nourishes the avian retina.

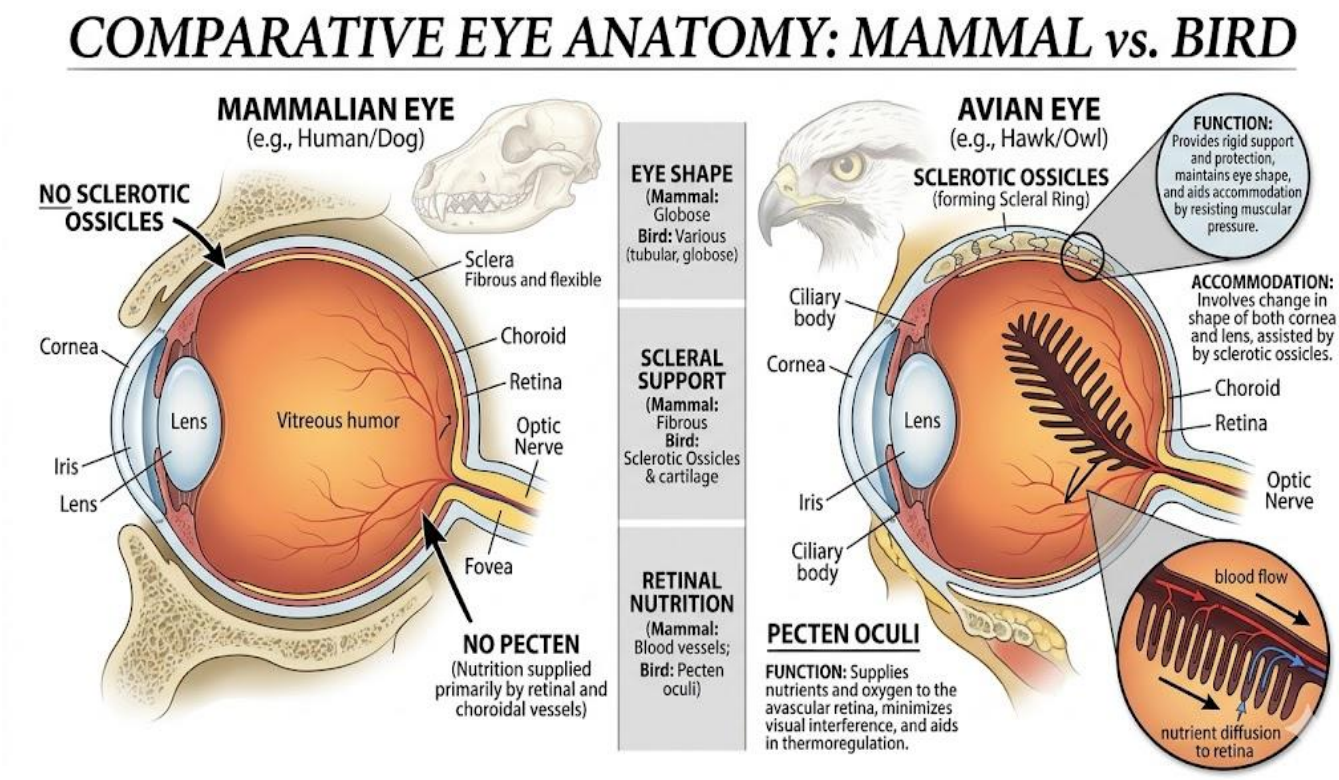

Figure 5.2: Diagram comparing the mammalian and avian eye in cross-section

5.1.3 Common eye conditions in farm animals

Infectious bovine keratoconjunctivitis (IBK or pink eye) is the most common eye disease of cattle, caused by Moraxella bovis; it presents as corneal ulceration, excessive tearing,

photophobia, and temporary blindness; spread is aided by flies (Musca autumnalis) and ultraviolet radiation. Treatment involves topical and systemic antibiotics; fly control and shade reduce incidence. Contagious ovine ophthalmia (COO) is the equivalent condition in sheep, caused by Mycoplasma conjunctivae.

Silage eye (listeric uveitis) in ruminants is caused by Listeria monocytogenes ascending via the trigeminal nerve from poorly fermented silage; it causes severe anterior uveitis, hypopyon, and often results in permanent blindness. Entropion (inward rolling of the eyelid causing the eyelashes to abrade the cornea) is common in newborn lambs; it causes painful corneal ulceration and requires prompt correction by manual eversion or suturing. Cataract (opacity of the lens) occurs in older animals and in certain hereditary conditions.

Fill in the blank: Infectious bovine keratoconjunctivitis is caused by _____ bovis and presents as corneal ulceration, tearing, and temporary blindness; flies spread the causative organism between cattle.

Condition	Species	Cause	Clinical signs
Pinkeye (infectious bovine keratoconjunctivitis)	Cattle	*Moraxella bovis* infection, spread by flies/dust	Lacrimation, photophobia, corneal opacity, ulceration
Silage eye	Cattle	*Listeria monocytogenes* from contaminated silage	Conjunctivitis, keratitis, ocular discharge
Entropion	Sheep (lambs)	Genetic or acquired eyelid inversion	Eyelid rolling inward, corneal irritation, tearing
Conjunctivitis	Cattle, sheep, goats	Bacterial, viral, or irritant causes (dust, ammonia)	Redness, swelling, discharge, rubbing eyes
Uveitis	Horses, cattle	Immune-mediated, trauma, infectious agents	Pain, photophobia, miosis, cloudy anterior chamber
Cataracts	Cattle, horses	Congenital, nutritional deficiencies, trauma	Lens opacity, impaired vision, blindness

Box 5.1: Common eye conditions in farm animals

1. Name the three layers of the mammalian eye and state the components within each.
2. Explain the functions of rods and cones in the retina.
3. State two ways in which the avian eye differs from the mammalian eye.
4. Explain the significance of direct brain photoreception in poultry production.
5. Describe infectious bovine keratoconjunctivitis (IBK) and state two methods of control.

5.2 The Ear

5.2.1 Structure of the mammalian ear

The mammalian ear has three divisions. The outer ear consists of the auricle (pinna), which collects sound waves and funnels them into the external auditory canal (meatus) to the tympanic membrane (eardrum). The middle ear is an air-filled cavity containing three small bones (ossicles): the malleus, incus, and stapes; they amplify and transmit vibrations from the tympanic membrane to the oval window of the inner ear. The Eustachian tube connects the middle ear to the pharynx, equalising air pressure.

The inner ear contains two functional systems: the cochlea (hearing) and the vestibular apparatus (balance). The cochlea is a fluid-filled spiral structure containing the organ of Corti, which bears hair cells that convert mechanical vibrations into electrical nerve impulses transmitted via the cochlear nerve to the auditory cortex. The vestibular apparatus consists of three semicircular canals (detecting rotational movement) and the utricle and saccule (detecting linear acceleration and gravity). Together they provide the sense of spatial orientation.

Fill in the blank: The three small bones (ossicles) of the middle ear are the malleus, _____, and stapes; they amplify and transmit vibrations from the eardrum to the oval window.

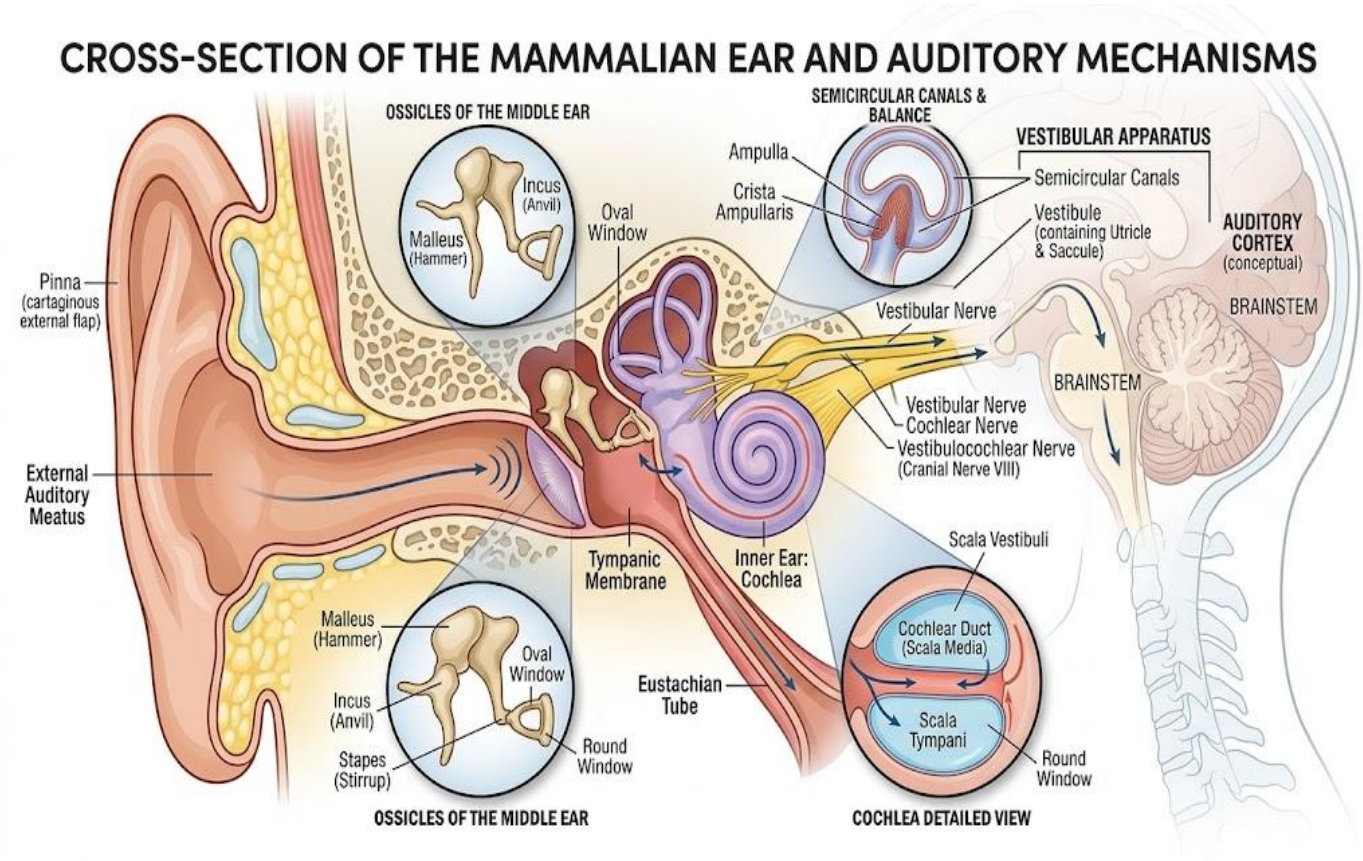

Figure 5.3: Cross-section diagram of the mammalian ear showing outer, middle, and inner divisions

5.2.2 The avian ear

Birds lack an external pinna; the ear opening is covered by feathers (auricular feathers) that protect it while allowing sound transmission. The avian outer ear leads to the tympanic membrane. The middle ear contains only one ossicle, the columella (equivalent to the mammalian stapes), rather than the three ossicles of mammals. The columella transmits vibrations from the tympanic membrane directly to the oval window of the inner ear, which is proportionally similar in function to the mammalian inner ear.

The avian cochlea (lagena) is shorter and straighter than the mammalian cochlea but achieves very high temporal resolution, allowing birds to discriminate sound sequences up to ten times faster than mammals. This is important for bird communication, song learning, and the rapid processing of environmental sounds. In poultry production, sound stress (continuous loud noise

from machinery) reduces feed intake, increases stress hormone levels, and impairs production performance, highlighting the importance of the auditory system in welfare management.

Fill in the blank: The avian middle ear contains only one ossicle called the _____, equivalent to the mammalian stapes, which transmits vibrations from the tympanic membrane to the inner ear.

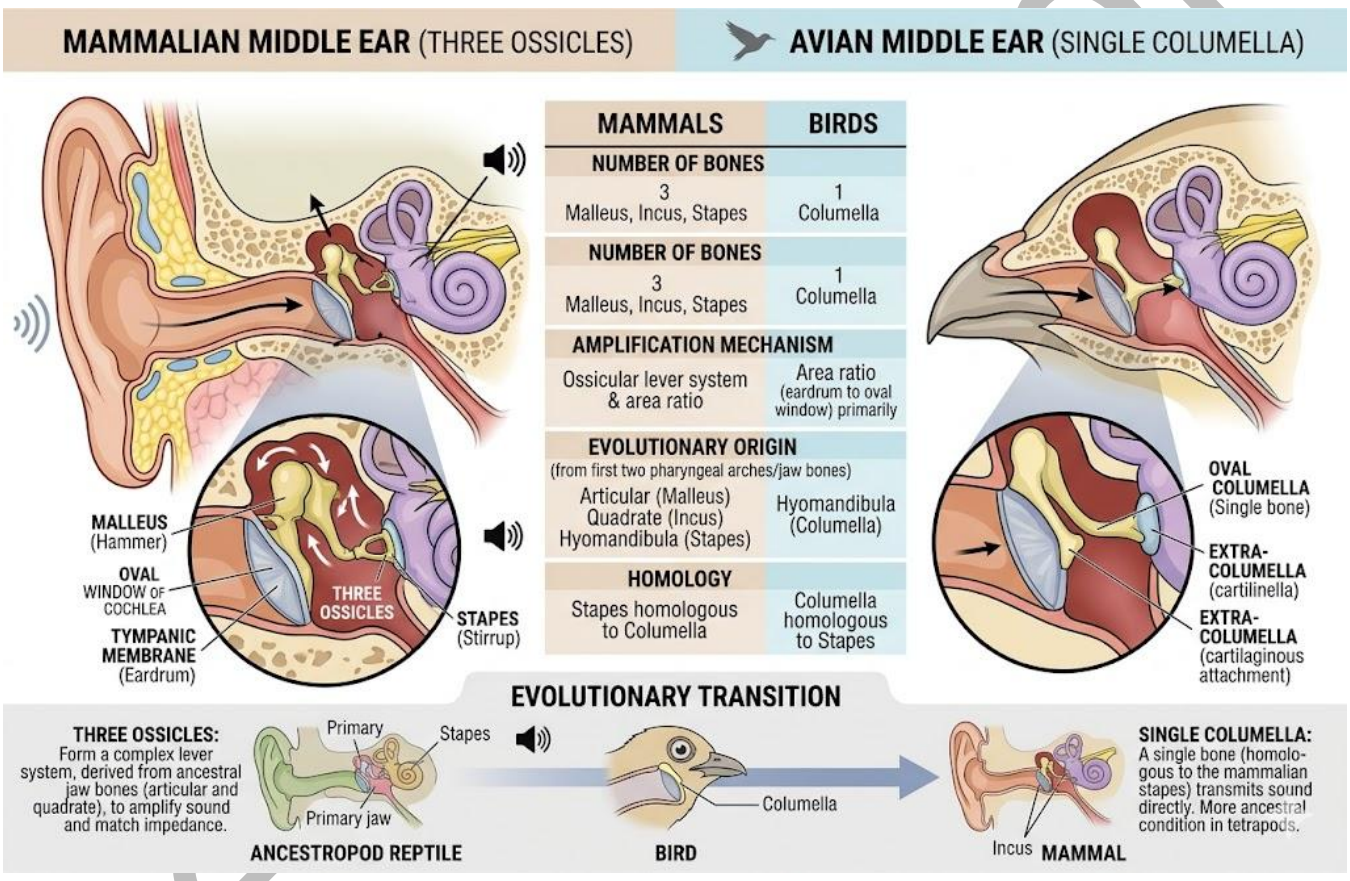

Figure 5.4: Diagram comparing the middle ear of a mammal and a bird

5.2.3 Common ear conditions in farm animals

Otitis externa (inflammation of the external auditory canal) is caused by bacterial or fungal infection, mites (Psoroptes cuniculi in rabbits and goats), or foreign bodies. Affected animals shake their head frequently, scratch at the ear, and may tilt the head. Otitis media (middle ear infection) often develops by extension from otitis externa or from respiratory tract infections via the Eustachian tube; in piglets it causes vestibular signs including head tilt and circling.

Listeriosis in ruminants can cause otitis media and inner ear damage when Listeria monocytogenes reaches the inner ear via the blood, producing severe head tilt, rolling, nystagmus, and facial nerve paralysis; it may be associated with poorly fermented silage. Aural plaques in horses (hyperkeratotic lesions in the ear canal caused by papillomavirus) cause discomfort and head shaking. In poultry, swollen head syndrome (Avibacterium paragallinarum or Newcastle disease virus) can involve the periorbital and periauricular tissues causing head swelling.

Fill in the blank: Otitis _____ is infection of the middle ear that can extend from the outer ear or ascend via the Eustachian tube; in piglets it causes head tilt, circling, and vestibular signs.

Condition	Species	Cause	Clinical signs
Aural hematoma	Cattle, sheep, goats	Trauma from head shaking or ear scratching	Swollen, fluctuant ear flap, discomfort
Otitis externa	Cattle, goats, pigs	Bacterial or parasitic infection (mites, flies)	Ear scratching, head shaking, discharge, foul odor
Otitis media/interna	Cattle, pigs	Extension of respiratory infections (e.g., *Mycoplasma*, *Pasteurella*)	Head tilt, circling, facial nerve paralysis, imbalance
Ear mites	Goats, sheep, rabbits (occasionally cattle)	*Psoroptes* or *Otodectes* infestation	Intense pruritus, crusting, thick discharge
Photosensitization lesions	Sheep, cattle	Ingestion of photodynamic plants or liver dysfunction	Ulceration, crusting, necrosis of ear tips
Foreign bodies	All species	Grass seeds, dirt, parasites	Irritation, head shaking, localized inflammation

Box 5.2: Common ear conditions in farm animals

Pilot questions 5.2

1. Name the three divisions of the mammalian ear and state the main structure and function of each.

2. Explain the role of the organ of Corti in hearing.
3. State two structural differences between the mammalian and avian ear.
4. Describe otitis media in piglets and state its main clinical signs.
5. Explain how sound stress can affect poultry production performance.

5.3 The Integumentary System

5.3.1 Structure and functions of the skin

The skin is the largest organ of the body and consists of two main layers. The epidermis is the outer avascular layer of stratified squamous epithelium; its deepest cells (stratum basale) divide continuously, pushing cells outward where they flatten, accumulate keratin, and eventually die to form the protective stratum corneum. The dermis is the thick inner layer of dense fibrous connective tissue containing blood vessels, lymphatics, nerve endings, hair follicles, sweat glands, and sebaceous glands. Beneath the dermis is the hypodermis (subcutis), a layer of loose connective tissue and adipose.

The skin performs six functions: protection (physical barrier against microorganisms, UV radiation, and mechanical trauma), thermoregulation (sweating and vasodilation for heat loss; vasoconstriction and piloerection for heat conservation), sensation (receptors for touch, pressure, pain, and temperature), excretion (sweat removes water, salt, and small amounts of urea), vitamin D synthesis (UV radiation converts 7-dehydrocholesterol in the skin to vitamin D3), and waterproofing (keratin and sebum reduce water loss). In birds, the skin is thinner and lacks sweat glands; thermoregulation relies on panting and vascular heat exchange in the comb and wattles.

Fill in the blank: The skin performs six functions including protection, thermoregulation, sensation, excretion, vitamin D _____, and waterproofing via keratin and sebum.

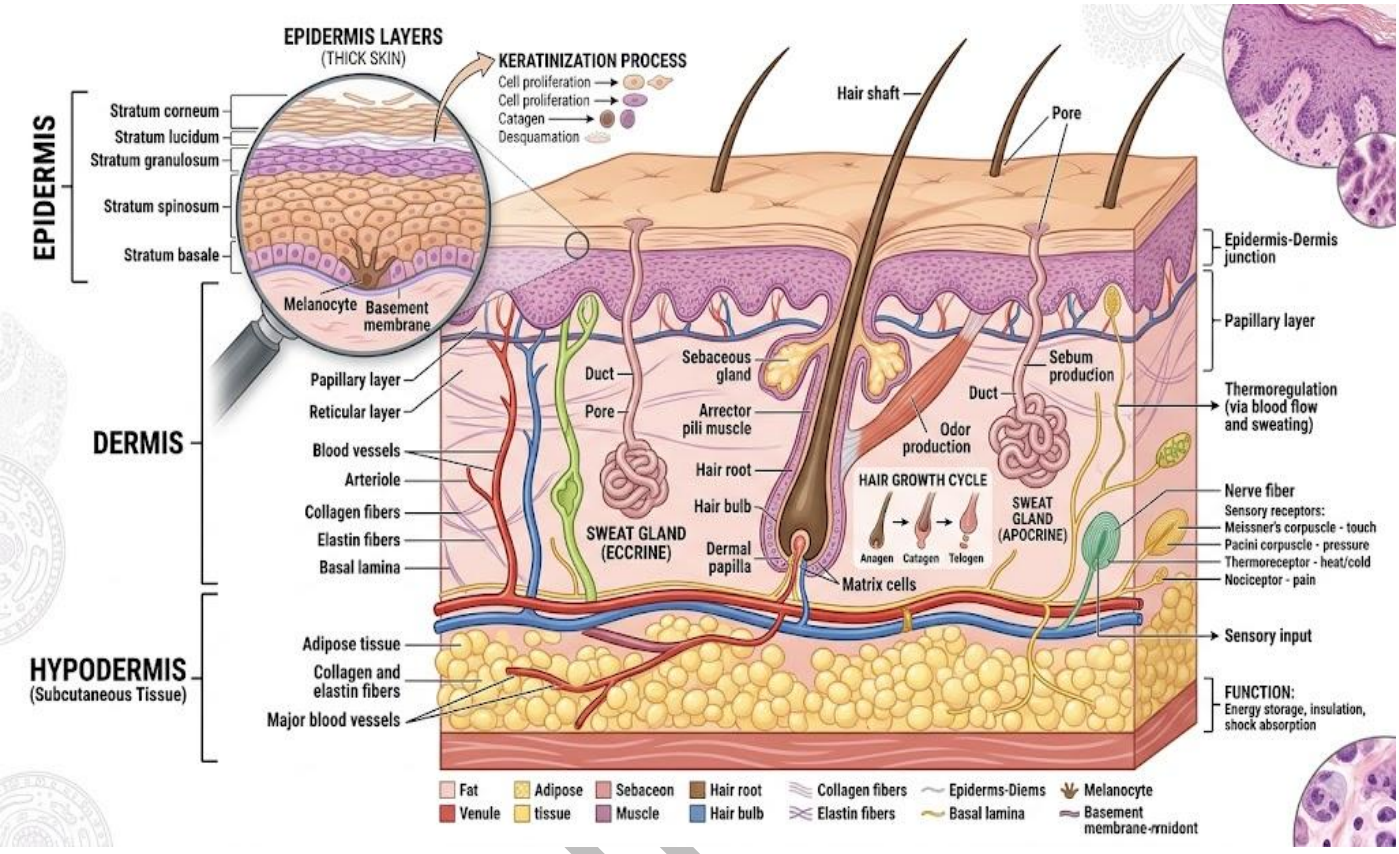

Figure 5.5: Cross-section diagram of mammalian skin showing epidermis, dermis, and hypodermis

5.3.2 Hair, wool, and feathers

Hair and wool grow from follicles in the dermis. A hair follicle consists of the follicle wall (outer and inner root sheaths), the hair bulb at the base (containing the matrix cells that divide to produce the hair shaft), and the dermal papilla (a knob of vascular connective tissue that nourishes the bulb). The sebaceous gland attached to each follicle secretes sebum to lubricate and waterproof the hair and skin surface. The arrector pili muscle attached to each follicle causes piloerection (hair standing on end) in response to cold or fear.

Wool in sheep grows continuously from primary and secondary follicles and is characterised by fine crimped fibres with overlapping scales (cuticle) that allow felting. Wool quality is described by fibre diameter (microns), staple length (cm), and staple strength. Feathers grow from feather follicles; the main types are contour feathers (covering the body and forming the flight surface),

down feathers (insulation), and filoplumes (sensory). Moulting is the periodic replacement of feathers; in laying hens, a forced moult can be used to reset the laying cycle.

Fill in the blank: Wool grows from _____ and secondary follicles in the dermis of sheep and is characterised by fine crimped fibres whose overlapping scale structure allows felting.

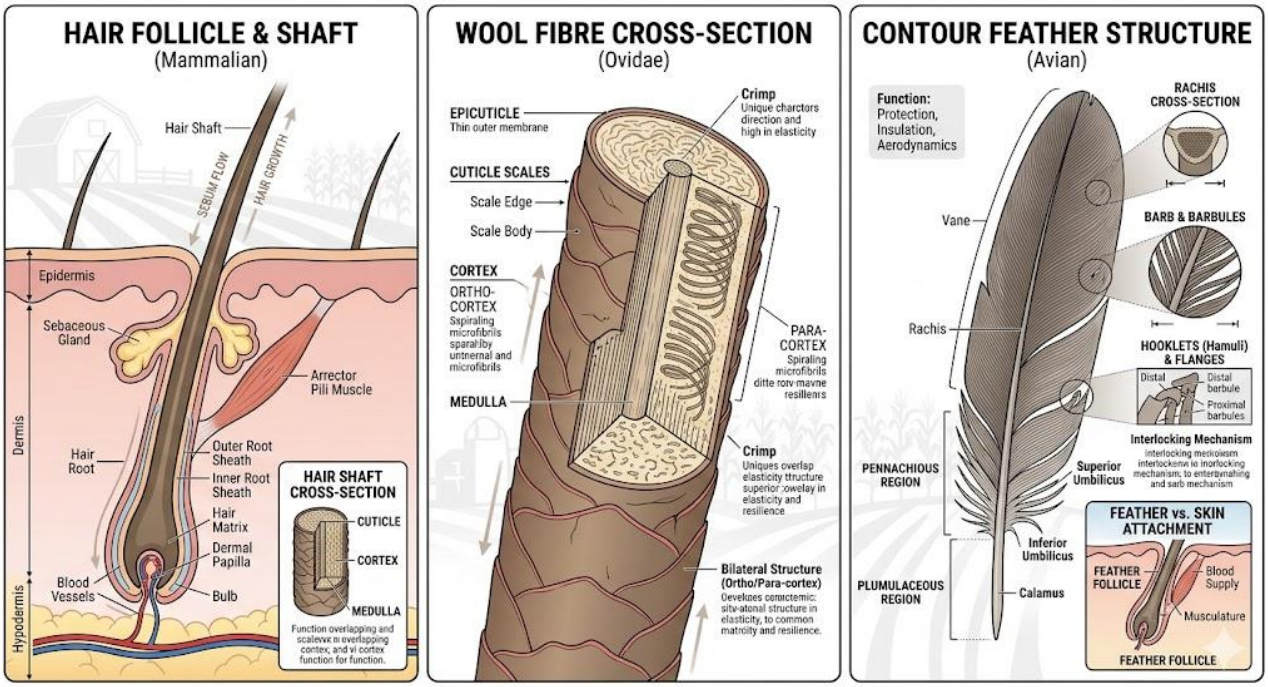

Figure 5.6: Diagram comparing the structure of a hair follicle, a wool fibre, and a contour feather

5.3.3 Hooves, claws, and horns

The hoof of cattle and horses is a modified keratinised structure enclosing and protecting the distal phalanx (pedal bone). The hoof wall (hard outer horn) is produced by the coronary band (coronet) at the top of the hoof and grows downward at approximately 5 to 8 mm per month; it is the primary weight-bearing structure. The sole (the bottom of the hoof) and the frog (horses only, a soft wedge-shaped structure on the sole) complete the hoof capsule. The sensitive laminae bond the hoof wall to the pedal bone; inflammation of these laminae causes laminitis.

Claws in cattle consist of two main digits (digits III and IV), each with its own hoof capsule. Regular hoof trimming (every 6 to 12 months) is essential in housed cattle to prevent overgrowth and corrective trimming is the primary treatment for claw disorders including sole ulcers, white

line disease, and digital dermatitis. Horns are keratinised outgrowths from the frontal bone produced by the horn corium; they grow continuously in cattle, goats, and sheep. Disbudding (destroying the horn bud in calves under 2 weeks old) and dehorning (in older animals) are performed to reduce injury risk.

Fill in the blank: The hoof wall is produced by the _____ band at the top of the hoof and grows downward at approximately 5 to 8 mm per month, forming the primary weight-bearing structure.

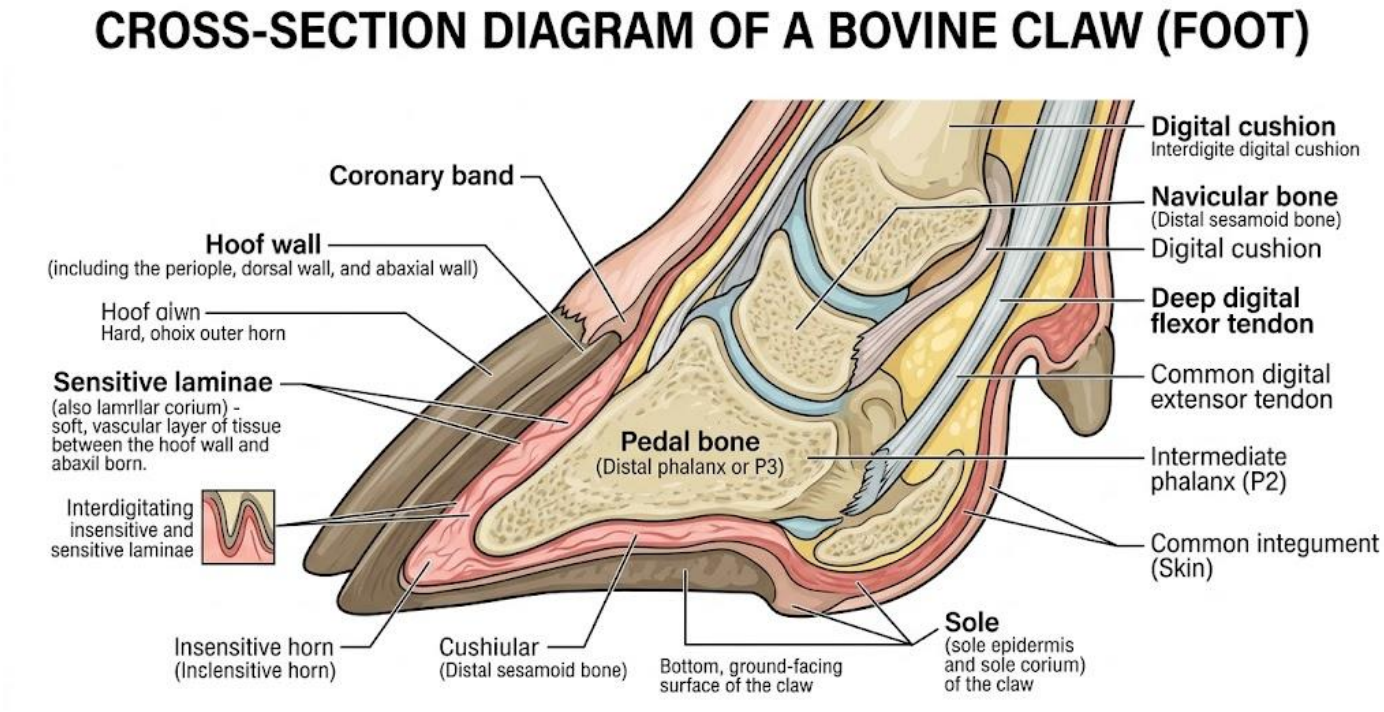

Figure 5.7: Cross-section diagram of the bovine claw showing the hoof wall, sole, sensitive laminae, and pedal bone

Pilot questions 5.3

1. Name the two main layers of the skin and state two structural features of each.
2. State six functions of the skin.
3. Describe the structure of a hair follicle naming four components.
4. Explain what the coronary band does and state its clinical significance.
5. Explain why regular hoof trimming is important in housed dairy cattle.

5.4 External Features and Body Condition

5.4.1 External features and species identification

External features are the visible characteristics used to identify species, breeds, sex, and age of farm animals. Key external features in cattle include coat colour and pattern (breed-specific), horn status (polled or horned), body conformation (shape and proportions of the trunk and limbs), udder development, and secondary sex characteristics (scrotal development in males). In sheep, face and leg colour, wool characteristics, and horn status distinguish major breeds. In goats, ear size and conformation (lop-eared vs erect-eared) and beard presence are distinguishing characters.

In pigs, ear size and orientation (erect vs lopped), jowl development, back line (straight vs dished), and body depth identify breeds. In poultry, comb type (single, rose, pea, buttercup, V-shaped), wattle size, plumage colour, feather distribution (feathered or clean-legged), skin colour, and eggshell colour are the principal breed characteristics. Age estimation in cattle uses tooth eruption and wear; the four pairs of permanent incisors erupt progressively between 2 and 5 years, allowing age estimation to within one year in young adults.

Fill in the blank: In cattle, age is estimated by examining the eruption and wear of the four pairs of permanent _____, which erupt progressively between 2 and 5 years of age.

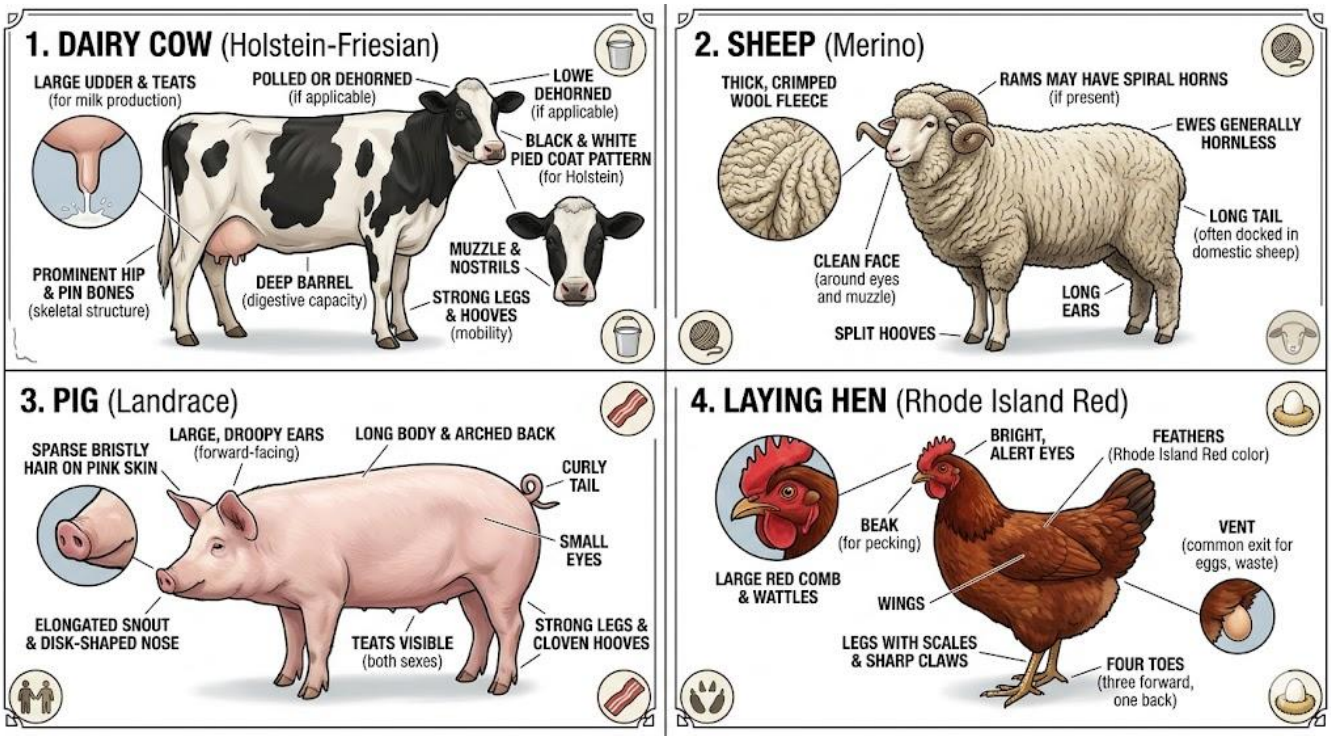

Figure 5.8: Plate showing external features of cattle, sheep, pig, and poultry used for breed identification

5.4.2 Body condition scoring

Body condition scoring (BCS) is a practical method of estimating subcutaneous fat reserves and overall nutritional status by palpating and visually assessing specific body sites. In cattle, BCS is assessed on a scale of 1 (emaciated) to 5 (obese) based on the prominence of the spine, tailhead, hip bones, and ribs, and the fullness of the tail head and flanks. In sheep, BCS is assessed on a 0 to 5 scale by palpating the lumbar vertebrae and the depth of muscle and fat over them. Target BCS at key reproductive events (mating, lambing, calving) optimises reproductive performance and neonatal health.

Thin animals (low BCS) mobilise body reserves, reducing immunity and reproductive performance; fat animals (high BCS) are at increased risk of dystocia, metabolic disease (fatty liver, ketosis in dairy cows), and reduced feed intake. Regular BCS monitoring allows nutritional interventions before clinical disease develops. In poultry, breast muscle scoring (assessing

pectoralis major prominence) is the equivalent tool; in pigs, backfat depth measured by ultrasound at the P2 point (65 mm from the spine at the last rib) is the standard method.

Fill in the blank: In cattle, body condition is scored on a scale of 1 (emaciated) to _____ (obese) by assessing the prominence of the spine, tailhead, hip bones, and ribs.

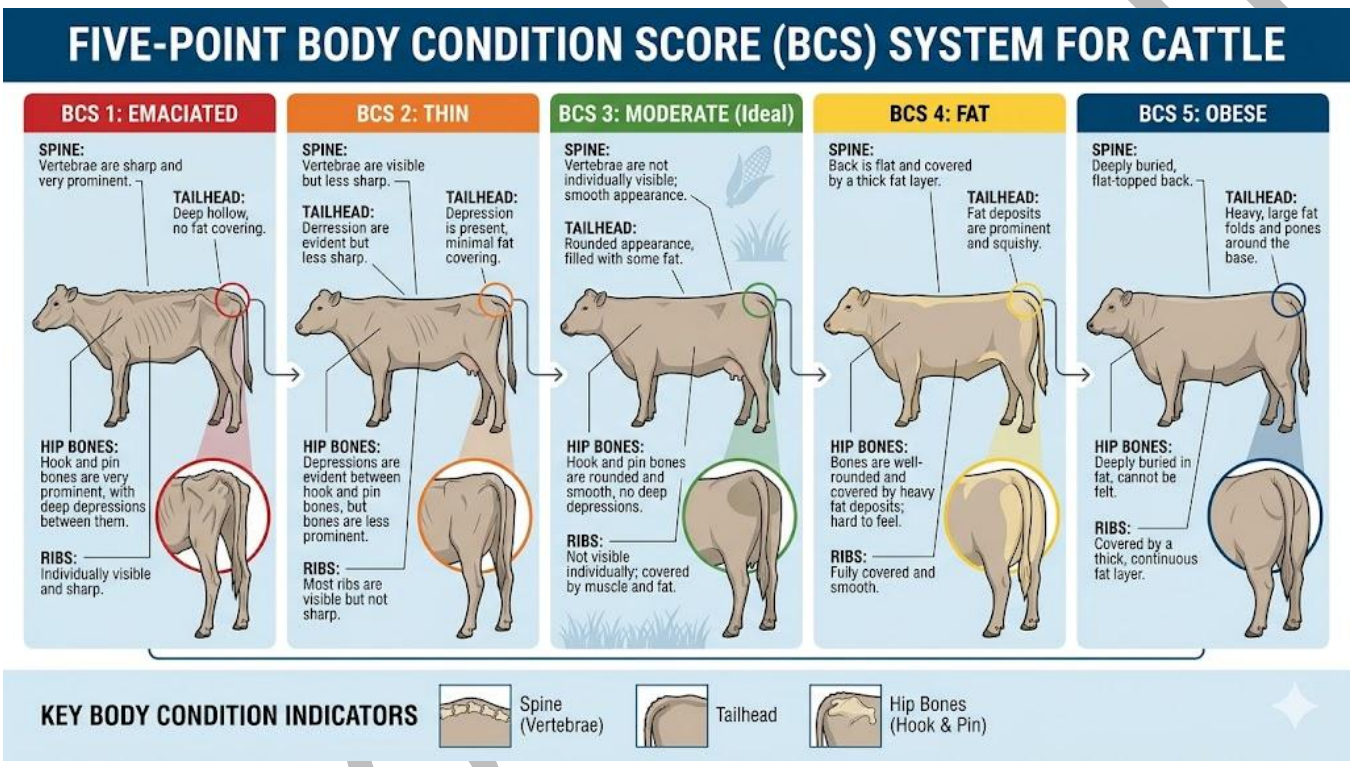

Figure 5.9: Diagram showing body condition scores 1 to 5 in dairy cattle with the key body landmarks assessed

5.4.3 External signs of health and disease

Routine observation of external signs allows early detection of disease before significant production loss or welfare compromise occurs. Signs of a healthy animal include: alert and responsive demeanour, bright eyes with no discharge, moist and clean nostrils, normal gait without lameness, smooth shiny coat or clean feathers, normal body temperature (cattle 38 to 39.5°C, sheep 38.5 to 40°C, pigs 38.5 to 39.5°C, chickens 40.5 to 41.5°C), normal respiratory rate, and adequate body condition score.

Signs of ill health include: dull or depressed demeanour, ocular or nasal discharge, laboured breathing, lameness, rough or staring coat, diarrhoea, skin lesions, swelling, and abnormal posture (arched back, tucked abdomen). In poultry, fluffed feathers, reduced activity, pale comb and wattles, and watery droppings indicate systemic illness. Recording and tracking these observations systematically (using a daily health check protocol) allows patterns to be identified, early interventions to be made, and the effectiveness of treatments to be monitored.

Fill in the blank: Normal body temperature in cattle is _____ to 39.5 degrees Celsius; a temperature above this range (pyrexia) is one of the most reliable early indicators of infection or inflammation.

Observation	Normal reference values	Notes
Temperature	Cattle: 38.5–39.5 °C; Sheep/Goats: 38.5–40 °C; Horses: 37.5–38.5 °C	Fever may indicate infection, inflammation, or stress
Respiration rate	Cattle: 26–50/min; Sheep/Goats: 20–40/min; Horses: 8–16/min	Observe for labored breathing, coughing, nasal discharge
Heart rate	Cattle: 60–80/min; Sheep/Goats: 70–90/min; Horses: 28–44/min	Tachycardia may signal pain, fever, or stress
Appetite & rumination	Normal feed intake; rumination in ruminants ~6–8 hrs/day	Reduced appetite or rumination suggests illness
Hydration status	Moist mucous membranes, normal skin elasticity	Dehydration shows as sunken eyes, dry gums, skin tenting
Mobility & posture	Normal gait, standing comfortably	Lameness, reluctance to move, or abnormal posture indicates musculoskeletal or hoof issues
Eyes, ears, nose	Clear, no discharge	Discharge, redness, or swelling may indicate infection
Coat & body condition	Smooth coat, appropriate body condition score (BCS)	Poor coat or low/high BCS signals nutritional or health problems
Manure/urine	Normal consistency and frequency	Diarrhea, constipation, or abnormal urine may indicate disease

Box 5.3: Daily health check protocol for farm animals

Pilot questions 5.4

1. Name four external features used to identify cattle breeds.
2. Explain how age is estimated in cattle from dentition.
3. Describe the body condition scoring system used in dairy cattle.
4. Explain the production consequences of low versus high body condition score in dairy cows.
5. State five external signs of a healthy farm animal and five signs of ill health.

Series Summary

This final Series described the sensory organs, integumentary structures, and external features of farm animals, completing the whole-body study of farm animal anatomy and physiology. We covered the three-layered mammalian eye, the mechanism of image formation by the retina, the distinctive avian eye with its sclerotic ossicles and pecten oculi, and the common eye conditions affecting farm animals (IBK, COO, silage eye, entropion). We then described the three-part mammalian ear, the mechanism of hearing via the organ of Corti, the avian ear with its single columella, and the ear conditions relevant to farm animal health.

We then described the two-layered skin and its six functions, the structure of hair follicles, wool fibres, and feathers, and the keratinised structures of hooves, claws, and horns with their management requirements. Finally, we examined external features for species and breed identification, body condition scoring in cattle, sheep, and pigs, and the systematic observation of external signs as the basis of daily health monitoring. By completing this Series and the course as a whole, you should be able to achieve all nine Series Learning Outcomes (SLO 5.1 to SLO 5.9) and all six course learning outcomes.

Glossary of Terms

- **Arrector pili:** a smooth muscle attached to each hair follicle; its contraction causes piloerection (hair standing on end) in response to cold or fear.

- **Aural plaques:** hyperkeratotic lesions in the ear canal of horses caused by papillomavirus; cause head shaking and ear sensitivity.
- **Bursa of Fabricius:** see Series 4; included here as context for its relationship to poultry immune function relevant to disease management.
- **Cataract:** opacity of the lens of the eye, reducing or eliminating the transmission of light to the retina; causes partial or total blindness.
- **Cochlea:** the fluid-filled spiral structure of the inner ear containing the organ of Corti; converts mechanical vibrations into electrical nerve impulses for hearing.
- **Columella:** the single ossicle of the avian middle ear, equivalent to the mammalian stapes; transmits vibrations from the tympanic membrane to the oval window.
- **Cornea:** the transparent anterior portion of the outer fibrous layer of the eye; the primary refractive surface through which light enters the eye.
- **Coronary band (coronet):** the junction between the skin and the hoof wall at the top of the hoof; produces the hoof wall horn at approximately 5 to 8 mm per month.
- **Dermal papilla:** a knob of vascular connective tissue at the base of a hair follicle that nourishes the hair bulb matrix cells producing the hair shaft.
- **Dermis:** the thick inner layer of skin composed of dense fibrous connective tissue; contains blood vessels, nerves, hair follicles, and glands.
- **Disbudding:** destruction of the horn bud in calves under 2 weeks of age to prevent horn growth; performed by chemical cautery or hot iron.
- **Entropion:** inward rolling of the eyelid causing the eyelashes to abrade the cornea; common in newborn lambs; causes painful corneal ulceration.
- **Epidermis:** the outer avascular layer of the skin composed of stratified squamous epithelium; forms the protective surface including the stratum corneum.
- **Eustachian tube:** the tube connecting the middle ear to the pharynx; equalises air pressure on either side of the tympanic membrane.
- **IBK (Infectious bovine keratoconjunctivitis):** the most common eye disease of cattle, caused by Moraxella bovis; presents as corneal ulceration, photophobia, and temporary blindness.

- **Iris:** the pigmented muscular diaphragm of the eye that controls pupil size and regulates the amount of light entering the eye.
- **Koilin:** the keratinised inner lining of the avian gizzard (covered in Series 3); also relevant here as a keratinised integumentary product in the context of avian keratinisation.
- **Lens:** the transparent biconvex structure behind the iris that focuses light on the retina by changing shape (accommodation) through the action of the ciliary muscle.
- **Organ of Corti:** the sensory organ within the cochlea containing hair cells that convert mechanical vibrations of the basilar membrane into electrical impulses; the basis of hearing.
- **Otitis externa:** inflammation of the external auditory canal caused by bacteria, fungi, or mites; causes head shaking and ear scratching.
- **Otitis media:** infection of the middle ear; in piglets causes vestibular signs including head tilt and circling.
- **Pecten oculi:** a comb-like vascular structure unique to birds projecting from the optic disc into the vitreous humour; nourishes the avian retina.
- **Piloerection:** the erection of hair or feathers by contraction of the arrector pili or equivalent muscles; conserves body heat and is a sign of pain or illness.
- **Retina:** the inner layer of the eye containing photoreceptors (rods and cones) that convert light into electrical signals transmitted by the optic nerve to the brain.
- **Sclerotic ossicles:** a ring of small bones embedded in the sclera of the avian eye that partially immobilise the eyeball, requiring birds to move the whole head to change the direction of gaze.
- **Sebaceous gland:** a gland associated with hair follicles that secretes sebum, a lipid-rich substance that lubricates and waterproofs the hair and skin surface.
- **Sclera:** the white, tough outer fibrous coat of the eye that maintains its shape and provides attachment for the extraocular muscles.
- **Stratum corneum:** the outermost layer of the epidermis consisting of dead, keratinised, flattened cells; forms the main barrier of the skin against physical, chemical, and microbial threats.
- **Uvea:** the middle vascular layer of the eye consisting of the choroid, ciliary body, and iris.

- **Vestibular apparatus:** the part of the inner ear containing the semicircular canals and otolith organs (utricle and saccule) that detect rotational movement and linear acceleration; provides the sense of balance.
- **White line disease:** separation and infection of the white line (the junction between the hoof wall and sole horn) in cattle, causing lameness; managed by corrective hoof trimming.
- **Wool staple:** a naturally cohering lock of wool fibres; described by staple length (mm) and staple strength (N/ktex); reflects ewe nutrition and health during the growing period.

Concept Check Questions [Series 5]

Objective Questions

1. The retina contains _____ for low-light vision and cones for colour vision. (Linked to SLO 5.1)
2. The _____ oculi is a unique vascular structure in birds projecting from the optic disc into the vitreous humour. (Linked to SLO 5.2)
3. The three ossicles of the mammalian middle ear are the malleus, incus, and _____. (Linked to SLO 5.4)
4. The hoof wall is produced by the _____ band and grows downward at approximately 5 to 8 mm per month. (Linked to SLO 5.7)
5. In dairy cattle, body condition is scored on a scale of 1 (emaciated) to _____. (Linked to SLO 5.9)

Short-Answer Questions

1. Describe the three layers of the mammalian eye and name one structure in each layer. (Linked to SLO 5.1)
2. State six functions of the skin. (Linked to SLO 5.5)
3. Describe the structure of the mammalian ear and explain how sound is converted to a nerve impulse. (Linked to SLO 5.4)
4. Explain body condition scoring in cattle and state the consequences of low and high BCS. (Linked to SLO 5.9)

5. State five external signs of a healthy farm animal. (Linked to SLO 5.9)

Long-Answer Questions

1. Describe the sensory organs of farm animals, covering the structure and function of the mammalian and avian eye and ear, highlighting key differences between species, and identifying the most clinically important conditions affecting each organ. (Linked to SLOs 5.1, 5.2, 5.3, 5.4)
2. Describe the integumentary system of farm animals, covering skin structure and functions, hair and wool follicle anatomy, feather types and moulting, and the structure and management of hooves, claws, and horns. (Linked to SLOs 5.5, 5.6, 5.7)
3. Evaluate the use of external features in farm animal management, explaining how breed and species identification is done, how body condition scoring is applied in cattle and sheep, and how a systematic daily health check using external signs supports early disease detection and production monitoring. (Linked to SLOs 5.8, 5.9)

Answers to Concept Check Questions [Series 5]

Objective Questions

1. Rods.
2. Pecten.
3. Stapes.
4. Coronary.
5. 5.

Short-Answer Questions

1. Outer fibrous layer: sclera (maintains eye shape) and cornea (transparent, light entry). Middle vascular layer (uvea): choroid (nourishes retina), ciliary body (produces aqueous humour, controls lens), iris (controls pupil size). Inner layer: retina (photoreceptors: rods for dim light, cones for colour; transmits image via optic nerve).
2. Protection (barrier against microorganisms, UV, and mechanical trauma); thermoregulation (sweating and vasodilation for heat loss; vasoconstriction and piloerection for heat conservation); sensation (touch, pain, temperature, pressure receptors); excretion (water, salt,

small amounts of urea via sweat); vitamin D synthesis (UV converts 7-dehydrocholesterol to vitamin D3); waterproofing (keratin and sebum reduce transcutaneous water loss).

3. Outer ear: pinna collects sound and funnels it via the external auditory canal to the tympanic membrane, which vibrates. Middle ear: the three ossicles (malleus, incus, stapes) amplify and transmit vibrations to the oval window of the inner ear. Inner ear cochlea: fluid vibrations stimulate hair cells of the organ of Corti, which generate electrical impulses transmitted via the cochlear nerve to the auditory cortex of the brain.
4. BCS assesses subcutaneous fat reserves on a 1 to 5 scale by palpating and observing the spine, tailhead, hip bones, and ribs; BCS 3 to 3.5 is target at calving. Low BCS: body reserve mobilisation reduces immunity and reproductive performance, increases susceptibility to disease. High BCS: increases risk of dystocia, fatty liver, and ketosis; reduces feed intake at calving, increasing metabolic disease risk.
5. Any five: alert and responsive demeanour; bright eyes without discharge; moist and clean nostrils; normal gait without lameness; smooth and shiny coat or clean feathers; normal body temperature for species; normal respiratory rate; adequate body condition score; normal feed and water intake.

Long-Answer Questions

1. Mammalian eye: three layers (fibrous: sclera, cornea; vascular uvea: choroid, ciliary body, iris; inner: retina with rods and cones); image formation (cornea refracts, lens focuses, retina converts to impulse, optic nerve to cortex); wide horizontal pupil in cattle for panoramic vision. Avian eye: larger relative to body, sclerotic ossicles restrict rotation, pecten oculi nourishes retina, two foveas, UV vision, deep brain photoreceptors control reproduction via hypothalamus-pituitary axis. Eye conditions: IBK (Moraxella bovis, corneal ulcer, fly spread, antibiotics, fly control); entropion (lambs, eyelid inversion, corneal abrasion); silage eye (Listeria, anterior uveitis, blindness). Mammalian ear: pinna, external canal, tympanic membrane; ossicles (malleus, incus, stapes); cochlea/organ of Corti (rods to nerve impulse); vestibular apparatus (balance). Avian ear: no pinna, single columella, straight lagena, high temporal resolution. Ear conditions: otitis externa (mites, bacteria, head shaking); otitis media (piglets, head tilt, circling); listeriosis inner ear damage.
2. Skin layers: epidermis (stratum basale to stratum corneum, avascular, keratinocytes); dermis (fibrous connective tissue, follicles, glands, nerves, vessels); hypodermis (adipose,

insulation). Six functions: protection, thermoregulation, sensation, excretion, vitamin D synthesis, waterproofing. Avian skin: thinner, no sweat glands, thermal regulation via panting and comb/wattle blood flow. Hair follicle: follicle wall, hair bulb, dermal papilla, sebaceous gland, arrector pili. Wool: primary and secondary follicles, crimped fibres, cuticle scales allow felting; quality by fibre diameter, staple length, staple strength. Feather types: contour (flight and body cover), down (insulation), filoplumes (sensory); moulting replaces feathers; forced moult resets laying cycle in hens. Hoof wall: produced by coronary band at 5 to 8 mm/month; sensitive laminae bond wall to pedal bone; laminitis from laminar inflammation. Hoof trimming every 6 to 12 months in housed cattle prevents overgrowth and treats sole ulcers, white line disease, digital dermatitis. Horns: keratinised, grow from horn corium over frontal bone; disbudding under 2 weeks; dehorning in older animals.

3. External features: cattle (coat colour, horn status, conformation, udder, sex characteristics); sheep (face and leg colour, wool, horn status); pigs (ear size, back line, jowl); poultry (comb type, plumage colour, feather distribution, skin colour). Age estimation by dentition: four pairs of permanent incisors erupt 2 to 5 years (2-tooth at 2 years, 4-tooth at 3 years, 6-tooth at 4 years, full mouth at 5 years). BCS: cattle 1 to 5 by spine, tailhead, hip, ribs; target 3 to 3.5 at calving; low BCS causes immune suppression and infertility; high BCS causes metabolic disease and dystocia. Sheep 0 to 5 by lumbar vertebrae palpation; pigs by P2 backfat ultrasound. Daily health check: demeanour, eyes, nose, breathing, gait, coat, temperature, faeces, production; normal temperatures (cattle 38 to 39.5°C, sheep 38.5 to 40°C, pigs 38.5 to 39.5°C, chickens 40.5 to 41.5°C); signs of ill health (dull, discharge, lameness, rough coat, abnormal temperature).

Answers to Pilot Questions [Series 5]

Part 5.1: The Eye

1. Outer fibrous layer: sclera (tough white coat maintaining shape and providing muscle attachment) and cornea (transparent anterior portion, primary refractive surface for light entry). Middle vascular layer (uvea): choroid (vascular layer nourishing the retina), ciliary body (produces aqueous humour and adjusts lens curvature via ciliary muscle), iris (muscular diaphragm controlling pupil size and light entry). Inner layer: retina (contains rods for dim

light/motion detection and cones for colour and detail; the site of image reception and neural transduction via the optic nerve).

2. Rods are photoreceptors sensitive to low light levels; they contain the pigment rhodopsin which bleaches in response to even small amounts of light, generating a nerve impulse; they provide black-and-white vision and are responsible for peripheral and night vision. Cones are photoreceptors concentrated in the fovea (area of highest acuity); they require brighter light to function; they contain different pigments sensitive to different wavelengths (red, green, blue) and provide colour vision and fine detail discrimination.
3. Any two: birds have sclerotic ossicles (a ring of bones in the sclera that partially immobilise the eye, so birds must turn the whole head to change gaze direction) while mammals have no ossicles and can rotate the eye freely. Birds have a pecten oculi (a comb-like vascular structure projecting from the optic disc into the vitreous, unique to birds, nourishing the avian retina) while mammals have no equivalent structure. Birds generally have a higher photoreceptor density, two foveas, and UV vision, while most mammals have one fovea and cannot see UV wavelengths.
4. In poultry, photoreception is not limited to the retina; light that penetrates the skull activates deep brain photoreceptors in the hypothalamus directly. These photoreceptors detect day length (photoperiod) and signal the hypothalamic-pituitary axis to regulate the secretion of gonadotropin-releasing hormone (GnRH), which controls follicle-stimulating hormone (FSH) and luteinising hormone (LH) release from the pituitary, which in turn regulate ovarian activity and egg production. In production, increasing day length from 8 to 16 hours of light per day stimulates onset of lay and maintains high egg production rates.
5. IBK is caused by Moraxella bovis, a Gram-negative bacterium that damages the corneal epithelium and produces proteolytic enzymes causing corneal ulceration. Clinical signs are excessive tearing (epiphora), blepharospasm (eye closure against photophobia), corneal cloudiness progressing to ulceration, and temporary or permanent blindness. Two methods of control: fly control (the face fly Musca autumnalis transmits M. bovis between cattle; insecticide ear tags, back rubbers, fly traps reduce transmission); shade provision (UV radiation damages the corneal epithelium and increases susceptibility; shaded housing or tree shade reduces UV exposure and disease incidence).

Part 5.2: The Ear

1. Outer ear: pinna (auricle, collects and directs sound waves) and external auditory canal (meatus, transmits sound to the tympanic membrane); function: sound collection and transmission. Middle ear: tympanic membrane (eardrum, vibrates in response to sound) and ossicles (malleus, incus, stapes, amplify and transmit vibrations to the oval window); air-filled cavity equalised by the Eustachian tube; function: mechanical amplification and impedance matching. Inner ear: cochlea (hearing, contains organ of Corti with hair cells that transduce vibrations to nerve impulses) and vestibular apparatus (semicircular canals, utricle, saccule; provides balance and spatial orientation).
2. The organ of Corti lies on the basilar membrane within the fluid-filled cochlea. When sound vibrations travel through the cochlear fluid, they cause the basilar membrane to vibrate; different regions of the basilar membrane vibrate maximally at different frequencies (high frequencies at the base, low frequencies at the apex). The vibration bends the stereocilia (hair bundles) of the hair cells on the organ of Corti; bending opens ion channels in the stereocilia, generating a receptor potential that triggers release of neurotransmitter onto cochlear nerve fibres; the cochlear nerve transmits impulses to the auditory cortex where they are interpreted as sound.
3. Any two: birds lack an external pinna (ear opening is covered by auricular feathers) while mammals have a prominent external pinna for sound collection. The avian middle ear contains only one ossicle (the columella) while the mammalian middle ear has three ossicles (malleus, incus, stapes), giving the mammalian system more stages of mechanical amplification. The avian cochlea (lagena) is straight while the mammalian cochlea is coiled into a spiral; despite being shorter, the avian cochlea achieves higher temporal resolution than the mammalian cochlea.
4. Otitis media in piglets is infection of the middle ear, often arising by extension from the nasopharynx via the Eustachian tube, typically caused by bacteria such as Mycoplasma hyorhinis or Streptococcus suis. The infection inflames the middle ear and damages the vestibular portion of the inner ear. Main clinical signs: head tilt (the affected ear tilts downward as the animal compensates for unilateral vestibular dysfunction), circling (the animal moves in circles toward the affected side), and nystagmus (rapid involuntary eye movement); severe cases cause falling, rolling, and inability to stand. Recovery may be incomplete even with antibiotic treatment.
5. The avian auditory system is sensitive to sound across a range relevant to detecting feeding, social, and alarm signals. Continuous loud noise from ventilation fans, feeding equipment, or processing machinery keeps birds in a low-level stress state that activates the sympathetic

nervous system, raising plasma corticosterone (the avian equivalent of cortisol). Elevated corticosterone suppresses immune function, reduces feed intake and feed conversion efficiency, and increases fearfulness and feather pecking. Monitoring and reducing noise levels in poultry houses (through equipment maintenance and building design) is a welfare intervention with measurable production benefits.

Part 5.3: The Integumentary System

1. Epidermis: stratified squamous epithelium, avascular, deepest layer (stratum basale) continuously divides, outermost layer (stratum corneum) is dead keratinised cells forming the physical barrier; Dermis: thick layer of dense fibrous connective tissue, highly vascularised; contains hair follicles (anchoring and nourishing hair), sebaceous glands (sebum secretion), sweat glands (thermoregulation and excretion), sensory nerve endings (touch, pain, temperature, pressure), and lymphatic vessels.
2. Protection (physical, chemical, and microbial barrier); thermoregulation (sweating and cutaneous vasodilation for heat dissipation; vasoconstriction, piloerection, and subcutaneous fat for heat conservation); sensation (mechanoreceptors, thermoreceptors, and nociceptors detecting environmental stimuli); excretion (water, sodium chloride, and small amounts of urea and lactic acid via sweat glands); vitamin D synthesis (UV radiation converts 7-dehydrocholesterol in keratinocytes to vitamin D3 that is hydroxylated in the liver and kidney to the active form); waterproofing (keratin in the stratum corneum and sebum secreted by sebaceous glands reduce transcutaneous water loss).
3. A hair follicle consists of: follicle wall (outer root sheath, continuous with the epidermis, and inner root sheath, which moulds the shape of the hair shaft); hair bulb (the expanded base of the follicle, containing the dividing matrix cells that produce the hair shaft and the melanocytes that pigment it); dermal papilla (a knob of vascular connective tissue indenting the base of the hair bulb, supplying nutrients to the matrix cells); sebaceous gland (opens into the follicle above the bulb, secretes sebum).
4. The coronary band (coronet) is the transitional zone between the skin and the hoof wall at the proximal border of the hoof; it contains the coronary corium, a highly vascularised layer of papillate dermis that produces the horn tubules of the hoof wall at a rate of approximately 5 to 8 mm per month. Clinically, any damage to the coronary band (injuries, laminitis vasculopathy, or infection) interrupts hoof wall production, creating a horizontal groove or

crack in the growing horn (a horizontal fissure or hardship groove) that reduces hoof wall integrity and predisposes to lameness.

5. In housed dairy cattle, the hoof does not wear naturally as it would on abrasive outdoor surfaces. Without regular trimming (every 6 to 12 months), the hoof wall and sole overgrow, changing the weight distribution on the claw and increasing pressure on the white line and sole, predisposing to white line disease (separation and infection of the white line junction) and sole ulcers (pressure necrosis of the sole corium over the flexor tuberosity of the pedal bone). These conditions cause severe lameness, reduce feed intake, milk production, and reproductive performance, and are among the most economically important health conditions of dairy cattle.

Part 5.4: External Features and Body Condition

1. Any four: coat colour and pattern (e.g. black-and-white Friesian, red Hereford with white face); horn status (polled breeds such as Aberdeen Angus versus horned breeds such as Longhorn); body conformation and proportions (dairy cattle: angular, prominent hip bones, large udder; beef cattle: heavily muscled, compact); udder development and attachment (breed differences in udder depth, fore attachment length, and teat placement); secondary sex characteristics (scrotal development in bulls, absence in steers and cows).
2. Cattle are born with eight deciduous (milk) incisors. The permanent incisors erupt in pairs (from medial to lateral) between approximately 2 and 5 years: the central pair (1st incisors) erupt at approximately 2 years (2-tooth mouth); the second pair at 3 years (4-tooth or 4-year mouth); the third pair at 4 years (6-tooth mouth); and the lateral corners (4th pair) at 5 years (full or 8-tooth mouth). After full eruption, progressive wear and spreading of the teeth continue with age, allowing rough estimates beyond 5 years. This method gives accuracy to within approximately one year in young adults.
3. Cattle BCS is assessed on a linear scale from 1 to 5: score 1 is severely emaciated (all bony prominences clearly visible, no fat or muscle cover); score 5 is obese (bony prominences not palpable, extensive fat deposits over the back, tailhead, and ribs). Assessment is made by visual inspection and manual palpation of: the spinous processes of the thoracic and lumbar vertebrae, the transverse processes of the lumbar vertebrae, the tailhead region, the hook (tuber coxae) and pin (tuber ischii) bones, and the short ribs. A score of 2.5 to 3.5 is considered optimal for most production stages.

4. Low BCS (below 2.0): indicates excessive body reserve mobilisation; in dairy cows this is associated with negative energy balance and ketonaemia, which suppress immune function, impair ovarian cyclicity and return to oestrus (extended calving interval), increase susceptibility to mastitis, metritis, and other periparturient diseases, and reduce milk yield. High BCS (above 4.0): fat cows are at increased risk of dystocia (difficulty calving due to fat deposition in the pelvic canal), fatty liver and hepatic lipidosis (excess mobilised fat overwhelms liver), ketosis, and displaced abomasum; fat cows also have reduced voluntary feed intake in early lactation, deepening negative energy balance.
5. Five signs of a healthy animal: alert and responsive demeanour (bright eyes, attentive to surroundings, reacts normally to approach); normal gait without lameness (weight-bearing equally on all four limbs, normal stride length); bright eyes with no discharge or cloudiness; moist, clean nostrils with no nasal discharge; normal body temperature within the species range (cattle 38 to 39.5°C). Five signs of ill health: dull or depressed demeanour (head down, separated from group, unresponsive); lameness (uneven weight distribution, shortened stride, reluctance to move); ocular discharge (watery, mucoid, or purulent discharge indicating infection or irritation); nasal discharge (watery or purulent indicating respiratory infection); rough, staring, or dull coat or fluffed feathers in birds (indicating systemic illness, pain, or nutritional deficiency).

References and Attributions [Series 5]

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Figures, Plates, Tables, and Boxes

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