Anatomy and Physiology of Domestic Animals

Second Edition

1 Introduction to anatomy and physiology

Contents

Although there are many good anatomy and physiology texts that focus on humans, there is a paucity of such options for animals. Since animals have distinct physiological and anatomical differences relative to humans, a human-focused text does not do the study of animals justice. Animals walk on four legs, whereas humans walk on two. Ruminant animals have adaptations to their digestive system that make them unique from humans. The respiratory system of birds differs from that of humans, thus making birds able to fly at high altitudes. The focus of this text will be to emphasize the anatomy and physiology of animals to appreciate their unique physiological systems.

Anatomy and physiology

Anatomy (derived from the Greek words meaning "to cut open") is the study of the morphology, or structure, of organisms. Thus, strictly speaking, anatomy deals with form rather than function. It can be divided into macroscopic (gross) or microscopic anatomy. Macroscopic anatomy deals with structure that can be seen with the naked eye, whereas microscopic anatomy deals with structure that can only be seen with the aid of a microscope. It is also important to appreciate that it is also much more than simply looking at smears of cells or stained tissue sections. Use of immunocytochemistry, fluorescence-labeled markers, multispectral cameras and sophisticated imaging software, and so on is revolutionizing our understanding of cell and tissue biology. Figure 1.1 provides an example of the ability to localize specific proteins within various cells of the mammary gland.

Macroscopic anatomy can be approached in different ways. Regional anatomy, as the name implies, deals with all the structures, such as nerves, bones, muscles, and blood vessels, in a defined region such

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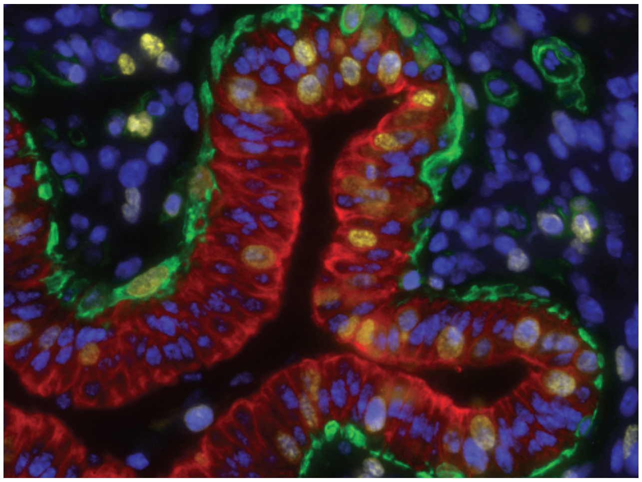


Fig. 1.1. Photomicrograph of a developing mammary duct. Taken from a Holstein calf, this tissue section was stained with specific antibodies and fluorescent tags to detect cell nuclei (blue), cytokeratin 18 (red, a marker specific for epithelial cells), CD10 (green, a marker of myoepithelial cells), and Ki67 (yellow, a protein produced in nuclei of cells that are about to divide). The tissue section is from a study to evaluate the effects of the ovary on ontogeny of myoepithelial cells in the bovine mammary gland. Image is courtesy of Dr. Steve Ellis, Clemson University.

as the head or hip. Systemic anatomy entails the study of a given organ system such as the muscular or skeletal system. It also involves the study of organ systems that are groups of organs that work together for a specific function, such as the digestive or urinary system. Surface anatomy considers markings that are visible from the outside. These may include knowledge of the muscles, such as sternocleidomastoid muscle, as a landmark to find another structure, such as the carotid artery.

Microscopic anatomy includes cytology and histology. Cytology is the study of the structure of individual cells that constitute the smallest units of life, at least in the sense of animal physiology. Histology is the study of tissues. Tissues are a collection of specialized cells and their products that perform a specific function. Tissues combine to form organs such as the heart, liver, and brain, and will be explained in greater detail in Chapter 4.

Developmental anatomy is the study of the changes in structure that occur throughout life. Embryology is a subdivision of developmental anatomy that traces the developmental changes prior to birth. Many systems of the body are not completely developed at birth, hence the need to continue to follow their development after parturition. Specific to farm mammals, understanding and management of the postnatal development of the mammary gland and reproductive system are essential for the success of dairies, cow/calf operations, flocks of sheep and goats, piggeries, and so on.

Physiology is the study of the function of living systems. While various systems will be presented separately throughout this book, it must be recognized that all systems work together to maintain the normal functioning of an animal. Therefore, the cardiovascular system does not work in isolation from the respiratory or nervous system, but instead they work in unison to coordinate the distribution of oxygen and removal of carbon dioxide throughout the body. As in anatomy, there are levels of complexity.

Cellular physiology is the study of how cells work. This includes the study of events at the chemical, molecular, and genetic levels. Organ physiology includes the study of specific organs, that is, cardiac or ovarian. Systems physiology includes the study of the functions of specific systems such as the cardiovascular, respiratory, or reproductive systems.

As you study anatomy and physiology, it will become apparent that structure and function have evolved to complement each other. The complementarity of structure and function is an essential concept. At multiple levels, a return to this fundamental idea will hasten your grasp of what sometimes seems to be an overwhelming amount of information and detail. But ultimately, the point is for you to understand how an animal works and to understand limitations. This relationship between form and function is evident beginning at the cellular level. For example, the epithelial cells that line the internal surface of the small intestine have so-called tight junctions that act to restrict the movement of materials into the body from the gastrointestinal tract, whereas the epithelial linings (endothelial cells) of capillaries have modified junctions. The linings of capillaries must be sufficiently porous to allow solutes to move readily in either direction across the capillary wall to nourish the tissue and remove waste products.

As another example, there are structural differences between birds and mammals that allow flight. Birds contain pneumatic bones, that is, bones that are hollow, which are connected to the respiratory system. These bones include the skull, humerus, clavicle, keel, sacrum, and lumbar vertebrae. In addition, the lumbar and sacral vertebrae are fused as an adaptation for flight. This provides yet another example of complementary structure and function.

Levels of organization

The animal body has a complex organization extending from the most microscopic levels up to the macroscopic (Fig. 1.2). Beginning with the smallest microscopic units of stability, the levels of organization are as follows:

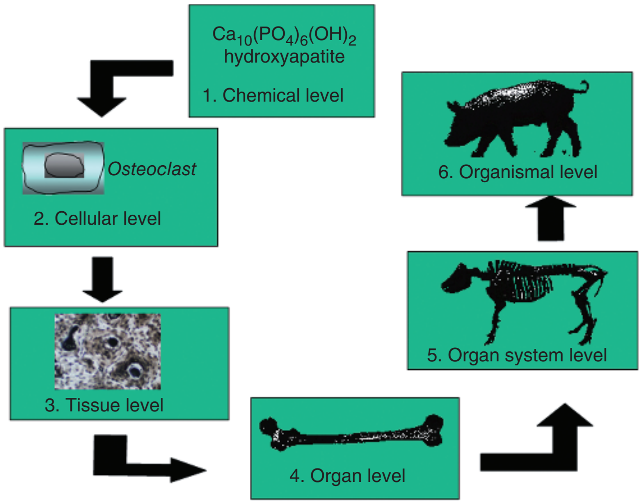


Fig. 1.2. Levels of organization. (1) Atoms interact to form molecules, which combine to form complex chemicals. (2) Chemicals combine to form cells that can display specific functions depending on the proteins expressed. (3) Cells having a common function combine to form tissue. (4) Tissues combine to perform a common function. (5) Organs can work together for a common function. (6) All the organ systems combine to produce a living animal.

- Chemical level. Atoms are the smallest units of matter that have properties of an element. They combine with covalent bonds to form molecules such as molecular oxygen (O_2), glucose ($C_6H_{12}O_6$), or methane (CH_4). The properties of various chemicals have a major influence on physiology. For example, at a low pH, a chemical may not be ionized and can thus cross a cellular membrane whereas above a certain pH, the same molecule may become ionized and thus unable to cross a lipid bilayer.
- Cellular level. As the smallest unit of life, cells have various sizes, shapes, and properties that allow them to carry out specialized functions. Some cells have cilium that allow them to move materials across their surfaces (i.e., the epithelial lining the bronchioles or cells lining the oviduct), whereas other cells are adapted to store lipids, produce collagen, or contract when stimulated.
- Tissue level. A tissue is a group of cells having a common structure and function. The four types of tissue include muscle, epithelia, nervous, and connective tissue.
- Organ level. Two or more tissues working for a given function form an organ. All four tissue types combine to form skin, the largest organ of the body, or the cochlea in the ear, the smallest organ of the body.
- Organ system level. Organs can work together for a common function. For example, the alimentary canal works with the liver, gallbladder, and pancreas to form part of the digestive system. The pancreas also functions as part of the endocrine system because of the pancreatic islets that produce insulin and glucagon. The organ systems include the integumentary, skeletal, muscular, nervous, endocrine, respiratory, digestive, lymphatic, urinary, and reproductive systems (Fig. 1.3).
- Organismal level. The organismal level, or the whole animal, includes all of the organ systems that work together to maintain homeostasis.

Homeostasis

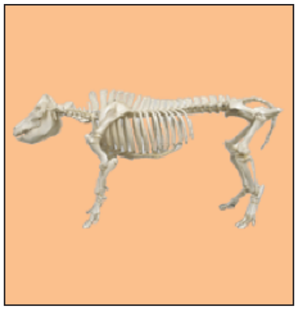
The 19th-century French physiologist Claude Bernard (1965) coined the term *milieu interieur*, which referred to the relatively constant internal environment, that is, extracellular fluid, in which cells live. Walter Cannon (1932), a 20th-century American physiologist, later coined the term *homeostasis*, meaning "unchanging" internal environment. While the concept of homeostasis is fundamental to understanding physiology, the term is better understood as a relatively steady state that is maintained within an animal despite a wide range of environmental conditions. In this way, various internal conditions, such as plasma glucose, electrolyte concentrations, or body temperature, are maintained within narrow limits through homeostatic mechanisms.

Homeostasis is maintained at all levels of life. Individual cells, for example, control their internal environment via selectively permeable membranes. These membranes will allow selective movement across the membrane based on such factors as pH, size, or whether there is a specific transport system for that compound. Whole animals maintain their internal environment by a host of behavioral and physiological mechanisms. A behavioral method of regulation may include moving from a sunny area to a shady area to decrease body temperature, whereas a physiological method may involve an increase in sweating or panting to accomplish the same goal.

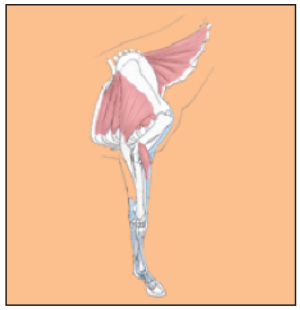
Homeostatic regulatory mechanisms

Elaborate regulatory mechanisms exist to maintain homeostasis. Homeostasis is maintained by the actions of the nervous and endocrine systems that communicate changes in the internal and external environment. The two systems work in conjunction to make relatively rapid or slow changes, respectively. The nervous system responds to immediate, short-term needs, as seen in a reflex arc in which an animal withdraws its foot after stepping on a sharp object. In contrast, the endocrine system generally elicits responses that last

a. Integumentary system: Forms the external covering of the body providing protection, preventing desiccation, supplying sensory information about the environment and synthesizing vitamin D.

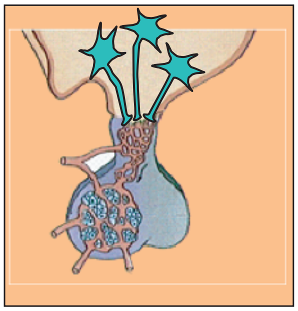


b. Skeletal system: Functions in support, protection, and movement. Also important in blood cell formation and mineral storage.



c. Muscular system: Functions in movement, maintains posture, and generates heat.

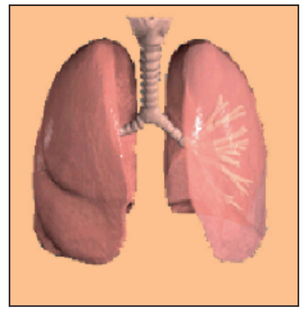
d. Nervous system: Through its functions of sensory input, integration, and motor output, it quickly helps the animal interact with the internal and external environment.



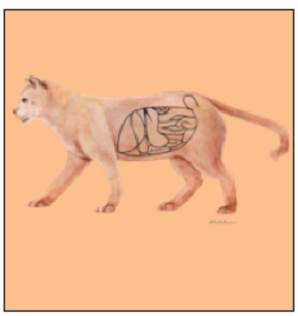
e. Endocrine system: Collectively, all the endocrine-secreting cells; these produce hormones that help maintain the internal environment.

f. Cardiovascular system: Includes blood vessels and the heart, which function to carry nutrients and waste throughout the body.

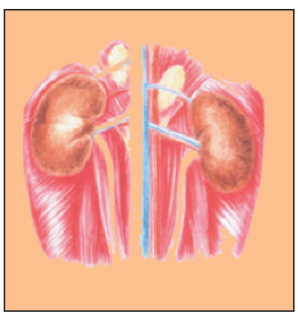
g. Lymphatic system: Returns excess interstitial fluid to the blood and contains phagocytic cells involved in immunity.



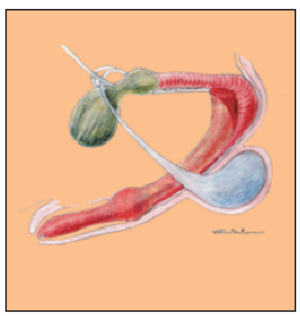
h. Respiratory system: Provides oxygen and eliminates CO_2.



i. Digestive system: Assimilation, breakdown, and absorption of nutrients. Provides important immunological barrier against external environment.



j. Urinary system: Eliminates nitrogenous wastes, maintains fluid and electrolyte balance, and has an endocrine function.



k. Reproductive system: Functions to produce offspring.

Fig. 1.3. Organ systems. The body consists of 11 major organ systems that are shown above along with examples of their components.

hours or days such as the release of insulin in response to a rise in blood glucose levels.

When regulation occurs at either the cellular, tissue, organ, or organ system level, it is termed autoregulation. For example, the presence of tryptophan in the small intestine will cause the local release of cholecystokinin (CCK) that will cause the pancreas to secrete enzymes. Extrinsic regulation, on the other hand, involves the coordinated action of both the nervous and endocrine systems. Such regulation occurs, for example, during prolonged stress where there is release of norepinephrine, epinephrine, and corticosteroids from the paired adrenal glands. This results in an increase in blood pressure and a change in blood flow such that there is an increase to the skeletal muscle and a decrease to the digestive tract.

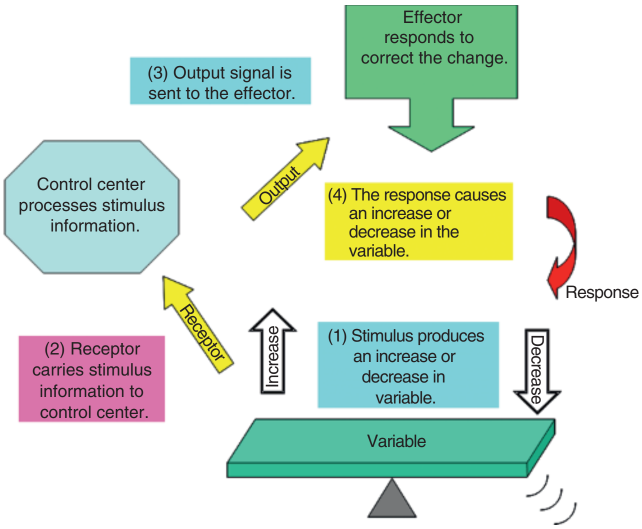


Fig. 1.4. Feedback systems. (1) A stimulus causes a change in a variable (i.e., plasma glucose, blood pressure, and heart rate). (2) A receptor senses the change in the variable and sends that information to the control center. (3) The control center compares the level of the variable to a set point and then initiates appropriate responses to change the variable. (4) The actions of the effectors bring about a change in the variable.

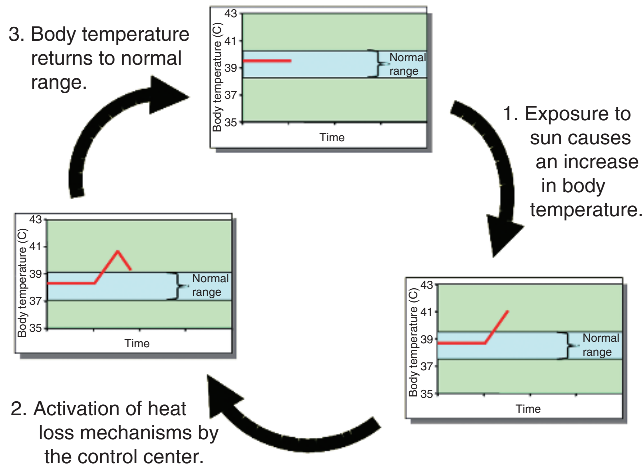


Fig. 1.5. Negative feedback systems. (1) A stimulus causes a change in a variable, in this example, an increase in body temperature. (2) Information regarding the increase in body temperature is carried to the control center, which activates appropriate heat loss mechanisms to decrease body temperature toward the set point. (3) As a result of the heat loss mechanisms, body temperature is returned to the set-point value, and homeostasis is maintained.

The factor being regulated is the variable. The regulatory mechanisms involve a receptor, a control center, and an effector. The receptor is a neuron that senses a change in the environment, called a stimulus. In response to the stimulus, the receptor carries an afferent (away) signal to the control center. The control center has a set point around which the variable is maintained. When the input signal is outside of the range of the set point, an appropriate response is elicited to correct the variable. An efferent (toward) signal is then sent to the effector. The effector induces a change in the controlled variable to bring it back to the set point (Fig. 1.4).

Feedback systems

Homeostatic regulatory mechanisms consist of either negative or positive feedback systems. Negative feedback systems are far more common than positive feedback systems.

Negative feedback system

In negative feedback systems, the control system initiates changes that counteract the stimulus (Fig. 1.5). This either reduces or eliminates the stimulus, thereby reestablishing the variable near its set point to maintain homeostasis. Using body temperature regulation as an example, every animal has a set point for body temperature, with the control center residing in the hypothalamus, a region of the brain. When the body temperature of an animal rises, possibly due to exposure to the sun, the warmth receptors located in the skin and hypothalamus sense a rise in temperature and send a signal to the hypothalamus. The hypothalamus compares these signals to the set point and then activates heat loss mechanisms (effector) such as sweating and vasodilation. Sweating results in evaporative cooling, while vasodilation increases the blood flow to the skin where heat is lost to the environment through radiation, conduction, and convection. The effector response results in a decrease in temperature back toward the set point.

While the negative feedback system acts to correct changes from the set point, it is also common for the set point to change under various conditions periodically throughout the day. When an animal gets a fever, the set point for body temperature increases. This results in the activation of heat production pathways, including shivering and vasoconstriction (Fig. 1.6). When the set point returns to normal, the animal activates heat loss mechanisms.

Positive feedback system

In response to a stimulus, the animal elicits regulatory mechanisms that augment or exaggerate the effect. This creates a regulatory cycle in which the response

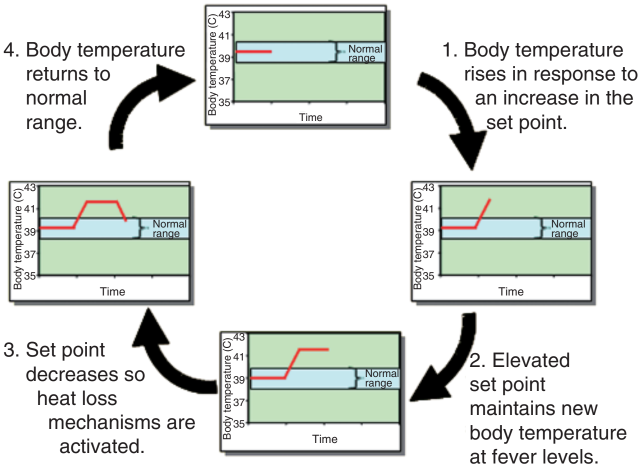


Fig. 1.6. Alterations in the homeostatic set points. The set point for a variable can change. For example, the development of a fever involves a change in the body temperature set point. (1) The control center responds to an increase in the set point for body temperature caused by a pyrogen (i.e., something that causes a fever) and activates heat production pathways. (2) After being raised to the elevated set point, body temperature is maintained at this new level. (3) The set point decreases either because the animal fights off the cause of the fever or has been given an antipyretic, so the set point decreases to the original value. The control center now detects that body temperature is elevated, and it activates heat loss mechanisms. (4) Body temperature is returned to normal.

causes an augmentation of the stimulus, which further increases the response. While positive feedback systems are rare, there are situations where they prove beneficial. In the case of blood clotting, an injured blood vessel secretes factors that attract platelets to that site. These platelets secrete factors that attract more platelets, and thus a positive cascade begins to occur. While this is beneficial in preventing the loss of blood, if left unchecked, the clotting process would continue until all the blood in the body was clotted, resulting in death.

Childbirth is another classic example of a positive feedback system. Near the time of parturition, oxytocin is produced by the fetus, which, along with prostaglandins, initiates uterine contractions. The uterine contractions cause the hypothalamus of the mother to release more oxytocin, causing greater uterine contractions. Thus, a positive feedback loop is initiated.

Anatomical nomenclature

As with any field of science, anatomy has its own language. It is necessary to know this language to describe structures and events in a precise and accurate manner. When trying to describe the location of the femur, simply saying that it is "in the back leg and located before the tibia and fibula" will not suffice.

Directional and positional terms

Anatomical terms are used to describe an animal that is in its normal anatomical position. In the case of humans, who are biped (i.e., walk on two legs), this means standing with the arms hanging by the side and the palms rotated forward. For animals that are quadruped (i.e., walk on four legs), anatomical position entails standing on all four limbs.

Positional and directional terms are presented in Table 1.1. The use of such terms allows for more precision while using fewer words to describe body structures. For example, one might say, "The knee is located on the front leg approximately halfway between the trunk and the hoof." With directional and positional terms, one can say, "The knee is located distal to the humerus and proximal to the radius and ulna, in the middle of the front leg."

These terms can have different meanings when referring to humans as opposed to animals. While dorsal and posterior mean toward the back or spinal column in humans, dorsal means toward the spinal cord in a quadruped, while posterior means toward the tail.

Body planes

When talking about anatomical locations, it is necessary to take into account the three-dimensional nature of an animal. The body can be sectioned, or cut, in all three planes. Knowing which plane one is observing when looking at a cross section gives knowledge of the location of various structures. Looking at anatomical planes has become common in the many television crime and medical mystery shows that show images from various magnetic resonance imaging (MRI) scans. Using the horse as an example, the terms are further depicted in Figure 1.7.

A sagittal plane divides the body into right and left parts along the longitudinal axis (Table 1.2; Fig. 1.7). If the plane is exactly along the midline of the longitudinal axis, it is said to be a median, or midsagittal, plane. Any sagittal plane other than the midsagittal is said to be a parasagittal (*para* = near) plane.

A frontal (dorsal) plane runs longitudinally and passes through the body parallel to its dorsal surface and at a right angle to the median plane. In other words, it divides an animal into a dorsal and ventral portion and runs parallel to the ground. In humans, such a plane runs perpendicular to the ground.

Table 1.1. Directional and positional terms.

Term	*Meaning*	*Example*
Dorsal	Toward the back; also, below the proximal ends of the carpus and tarsus, dorsal means toward the head (i.e., dorsal replaces cranial)	The vertebral column is dorsal to the sternum.
Ventral	Toward the belly	The udder is ventral to the tail.
Cranial	Toward the head	The neck is cranial to the tail.
Caudal	Toward the tail	The tail is caudal to the head.
Rostral	Part of the head closer to the nose	The beak is rostral to the ear.
Proximal	Near the trunk or origin of the limb	The elbow is proximal to the ankle.
Distal	Farther from the trunk	The ankle is distal to the elbow.
Palmar	Below the proximal ends of the carpus, palmar replaces caudal	The dewclaws are on the palmar surface of the forelimb.
Plantar	Below the proximal ends of the tarsus, planar replaces caudal	The dewclaws of the hind limb are on the plantar surface of the foot.
Medial	Toward the longitudinal axis (midline)	The sternum is medial to the limbs.
Lateral	Away from the longitudinal axis	The scapula lies lateral to the spine.
Superficial	Nearer the body surface	The skin is superficial to the ribs.
Deep	Farther from the body surface	The heart is deep to the ribs.
Axial and abaxial	Restricted to the digits, these terms indicate position relative to the longitudinal axis of the limb; axial and abaxial are closer and further to the longitudinal axis, respectively	The lateral edge of the hoof is abaxial to the phalanges.

Table 1.2. Body planes.

Orientation of Plane	*Plane*	*Description*
Perpendicular to long axis	Transverse	Divides the body into cranial and caudal parts; also crosses an organ or limb at a right angle to its long axis
Parallel to long axis	Median (midsagittal)	Divides body into equal right and left halves
	Sagittal	Divides body into unequal right and left halves
	Frontal (dorsal)	Longitudinal plane passing through the body parallel to dorsal surface and at right angles to the median plane

A transverse plane runs perpendicular to the long axis of the structure. A transverse plane can divide an animal into a cranial and caudal half, or it can divide a limb into a proximal and distal section.

Body cavities and membranes

A median view of an animal will reveal two cavities, the dorsal and ventral. The dorsal cavity protects the brain and spinal cord and contains the cranial cavity within the skull, and the vertebral, or spinal, cavity that is found within the vertebral column. The brain and the spinal cord are continuous; therefore, the cranial and vertebral cavities are also continuous.

When looking down the longitudinal axis, the trunk of the animal can be divided into three cavities. The thoracic cavity is surrounded by the ribs and muscles of the chest. It can be further subdivided into the pleural cavities, each of which houses a lung, and the mediastinum, which is located medially between the lungs and contains the pericardial cavity. The mediastinum also houses the esophagus and trachea.

The abdominopelvic cavity is separated from the thoracic cavity by the diaphragm. The abdominopelvic cavity has two components: the abdominal cavity that contains, among others, the stomach, intestines, spleen, and liver, as well as the more caudal pelvic cavity. The pelvic cavity is surrounded by the bones of the pelvis, and contains the bladder, part of the reproductive organs, and rectum.

The walls of the ventral body cavities, as well as the surface of the visceral organs, are covered by a thin, double-layer membrane called the serosa, or serous membrane. The portion of the serosa lining the body cavity is called the parietal (*parie* = wall) serosa, while the portion lining the organ is the visceral serosa.

The best way to visualize the relationship between the two layers of the serosa is to imagine pushing your

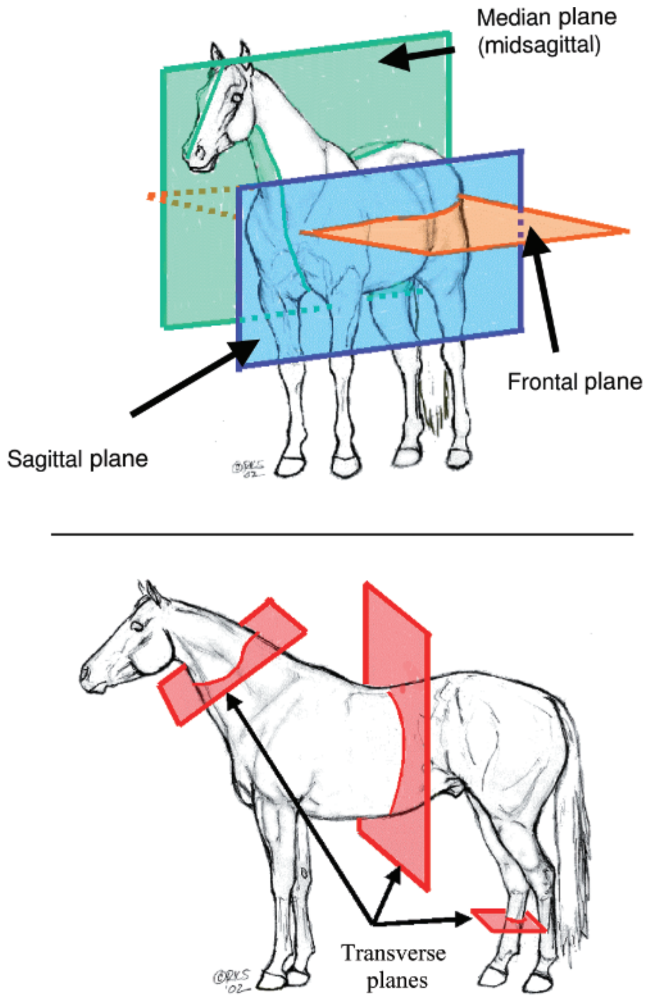


Fig. 1.7. Planes of the body. The three major planes (frontal, transverse, and sagittal) are shown.

fist into an inflated balloon. The layer of the balloon closest to your fist would be equivalent to the visceral serosa, while that part of the balloon on the outside would represent the parietal serosa. The two serosal membranes each secrete serosal fluid into the space between the two layers. This fluid acts as a lubricant to reduce the friction between the parietal and visceral serosa as they slide across one another. This is important when one considers how often the heart beats or the lungs inflate, during which time the visceral and parietal serosa slide across one another.

The serosa membranes have specific names depending on their locations. When found surrounding the heart, it is called the pericardium (*peri* = around + kardia, heart). Therefore, the parietal pericardium lines the pericardial cavity, while the visceral pericardium adheres to the heart. The pleura adheres to the lungs and lines the thoracic cavity, whereas the peritoneum lines the abdominopelvic cavity and adheres to the visceral organs.

Review questions and answers are available online.

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