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Introduction to Anatomy and Physiology

Although several good anatomy and physiology texts describe humans, there are fewer options focused on animals. The marked differences in physiology and anatomy of animals, compared to humans, mean that such texts are not generally suitable. For example, animals typically walk on four legs, whereas humans walk on two. Ruminant animals and birds have distinct adaptations to their digestive systems 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 is to emphasize the anatomy and physiology of animals to appreciate their unique anatomical and physiological adaptations.

Anatomy and Physiology

Anatomy (rooted in Greek meaning "to cut open") is the study of the morphology, or structure, of organisms. Consequently, anatomy deals primarily with form rather than function. Although certain anatomical arrangements allow for specialized physiological actions. For example, the counter current circulation in the legs of wading birds protects extremities in harsh weather. Alternatively, the exquisite microscopic structure of kidney nephrons allows the recovery of vital elements from filtered blood. The point is that form and function are intertwined. Appreciation of anatomy aids the understanding of physiology. Anatomy can be divided into macroscopic (gross) or microscopic anatomy. Macroscopic anatomy deals with structures that are visible with the unaided eye, whereas microscopic anatomy deals with structures visible only with the aid of a microscope. Students, researchers, and medical professionals have long recognized the value of viewing tissue samples or smears of biological fluids, e.g., blood smears and pap smears, to evaluate cellular function. However, advances in the use of immunocytochemistry, fluorescence-labeled markers, multispectral cameras, sophisticated imaging software, etc., are revolutionizing the understanding of cell and tissue biology. Figure 1.1 gives an example of the ability to localize specific proteins within various cell types in the bovine mammary gland.

There are various approaches for the study of macroscopic anatomy. Regional anatomy, as the name implies, deals with all the structures, such as nerves, bones, muscles, and blood vessels, in a defined region such as the head or hip. Systemic anatomy describes elements of a given organ system, such as the muscular or skeletal system. Similarly, the evaluation of groups of organs that work together for a specific function, such as the digestion or elimination of waste products, i.e., the urinary system, is also an appropriate study approach. Surface anatomy looks at the markings that are visible from the outside. These may include knowledge of the muscles, such as the sternocleidomastoid muscle, to be able 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.

Developmental anatomy is the study of the changes in structure that occur throughout life. Embryology, a subdivision of developmental anatomy, traces the developmental changes prior to birth. The reproductive system is rudimentary at birth, and hence, the need to continue to follow development after parturition. Specific to farm mammals, understanding and management of postnatal development of the mammary gland and reproductive systems are essential for the success of dairies, cow/calf operations, flocks of sheep and goats, piggeries, and so forth. It is now widely accepted that management decisions regarding nutrition, socialization, etc., of prepubertal animals can affect future performance.

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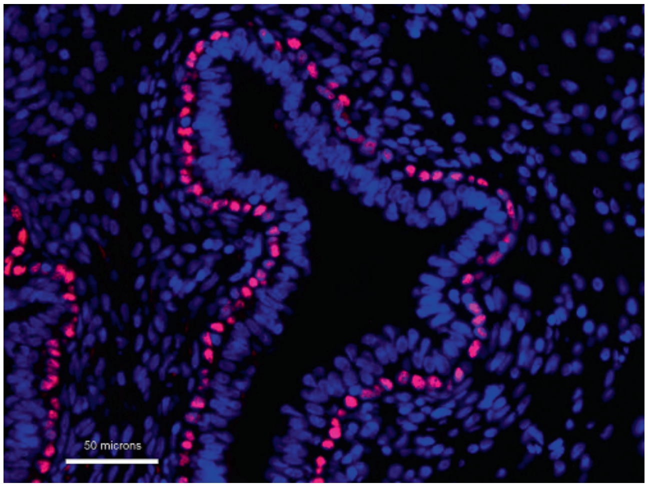

Fig. 1.1 Photomicrograph of mammary tissue from a prepubertal female bovine mammary gland. This tissue section stained with 4′,6-diamidion-2-phenylindole (DAPI) shows cell nuclei in blue. Red staining localizes an antibody against tumor protein p40, which is expressed in the nuclei of myoepithelial cells in the bovine mammary gland. Parsons et al. (2018)/with permission of Elsevier.

Physiology is the study of the function of living systems. Although various systems will be presented separately throughout this book, it is important to recognize that all these systems must work together to maintain normal function. Therefore, the cardiovascular system does not work in isolation from the respiratory or nervous system, but instead, it works in unison to coordinate the distribution of oxygen and the removal of carbon dioxide throughout the body.

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, i.e., cardiac or ovarian. Systems physiology includes the study of the function 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 understanding of what sometimes seems to be an overwhelming amount of information and detail. Ultimately, the point is for you to understand how an animal works and to understand its limitations. This relationship between form and function is evident beginning at the cellular level. For example, the epithelial cells lining the internal surface of the small intestine have tight junctions to restrict the movement of materials into the body from the gastrointestinal tract, whereas the epithelial cells lining capillaries (endothelial cells) have modified junctions. Why this difference? The lining of capillaries must be sufficiently porous to allow solutes to move readily in either direction across the capillary wall to nourish the tissues underneath and remove waste products.

As another example, there are structural differences between birds and mammals that allow flight. Birds have pneumatic bones, i.e., bones that are hollow and connected to the respiratory system. These bones include the skull, humerus, clavicle, keel, sacrum, and lumbar vertebrae. In addition, fusion of the lumbar and sacral vertebrae is an adaptation for flight. This illustrates yet another example of the complementary nature of structure and function, and thus the need to consider physiology and anatomy together.

Levels of Organization

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

- **Chemical Level**. Atoms are the smallest units of matter that have the 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 be ionized and thus unable to cross a lipid bilayer.
- **Cellular Level**. In animals, cells are the smallest unit of life. However, cells have various sizes, shapes, and properties that allow them to carry out specialized functions. Some cells have cilium that allows them to move materials across their

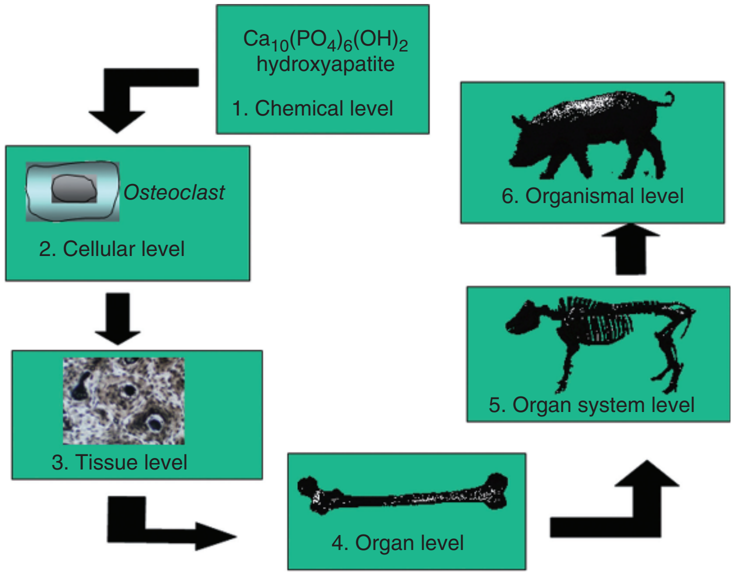

Fig. 1.2 Levels of organization. (1) Atoms interact to form molecules, which combine to form complex chemicals. (2) Molecules combine to form cells, which can display specific functions depending on the proteins expressed. (3) Cells having a common function combine to form tissue. (4) Tissues combine 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.

surfaces (i.e., the epithelial lining the bronchioles), 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 general types of tissue include muscle, epithelia, nervous, and connective tissue.
- **Organ Level**. Two or more tissues working for a given function constitute an organ. Each of the tissue types combines 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, gall bladder, and pancreas to form part of the digestive system. The pancreas also functions as part of the endocrine system. 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 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, i.e., extracellular fluid, in which cells live. Walter Cannon (1932), a 20th-century American physiologist, later coined the term *homeostasis* meaning “unchanging” internal environment. The concept of homeostasis is fundamental to understanding physiology. However, it does mean that the internal environment does not change. Rather, physiological systems function to maintain internal conditions within biologically acceptable boundaries. This happens despite exposure to a wide range of environmental conditions. In this way, various internal conditions such as the concentration of plasma glucose or electrolyte concentrations or body temperature remain 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 allow the selective movement of materials into and out of the cell. Transport depends on multiple factors, i.e., pH, size, or presence of a specific transport system for a particular agent. 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.

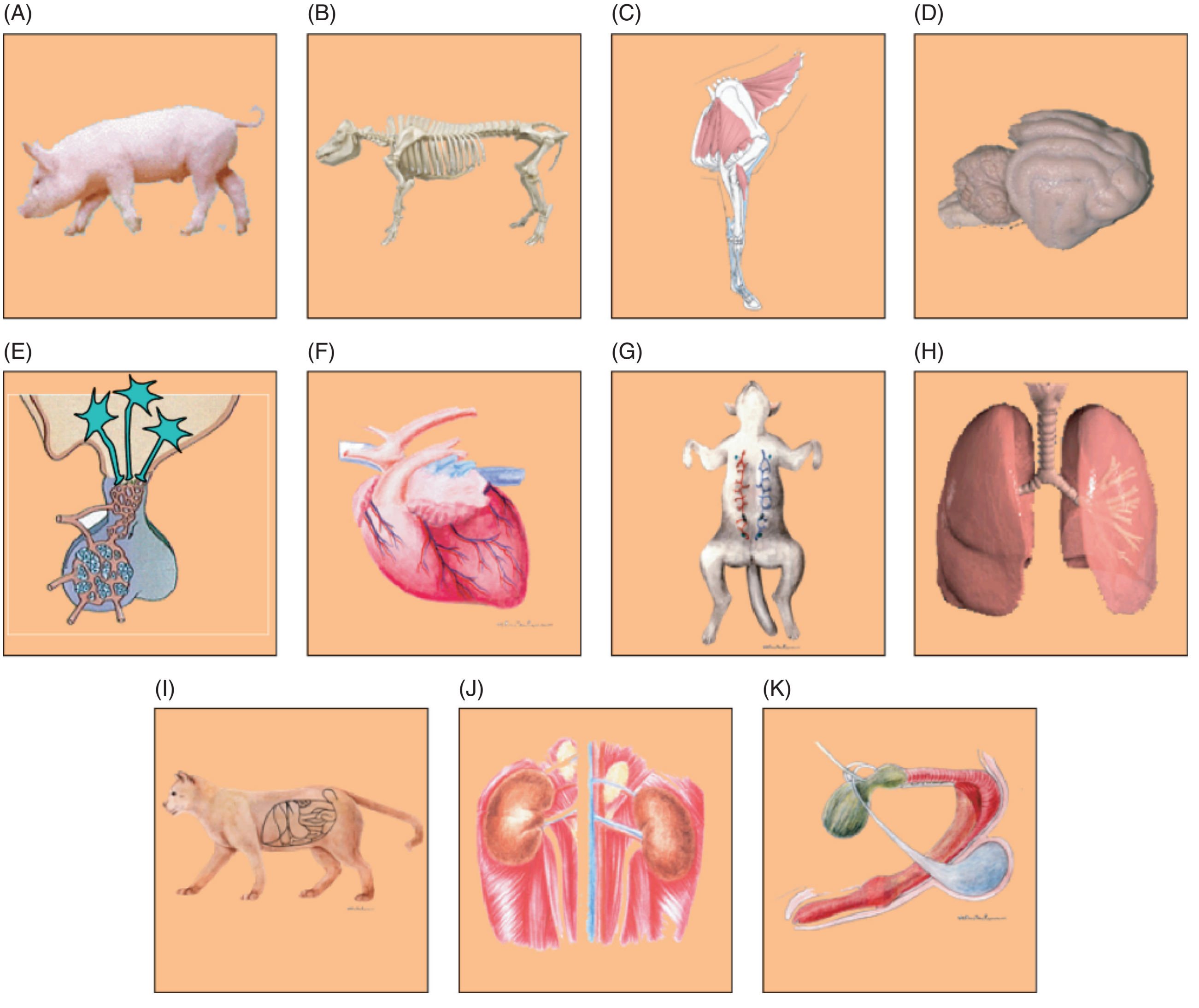

Fig. 1.3 Organ systems. The body consists of 11 major organ systems that are shown above along with examples of their components. (A) Integumentary system: forms the external covering of the body providing protection, preventing desiccation, supplying sensory information about the environment, and synthesizing 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 an important immunological barrier against the 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.

Homeostatic Regulatory Mechanisms

Elaborate regulatory mechanisms exist to maintain homeostasis. Homeostasis depends on 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, such 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 hours or days, such as the release of insulin in response to a rise in blood glucose levels.

Regulation that occurs at the cellular, tissue, organ, or organ system level is autoregulation. For example, the presence of tryptophan in the small intestine will cause the local release of cholecystokinin (CCK), which will cause the pancreas to

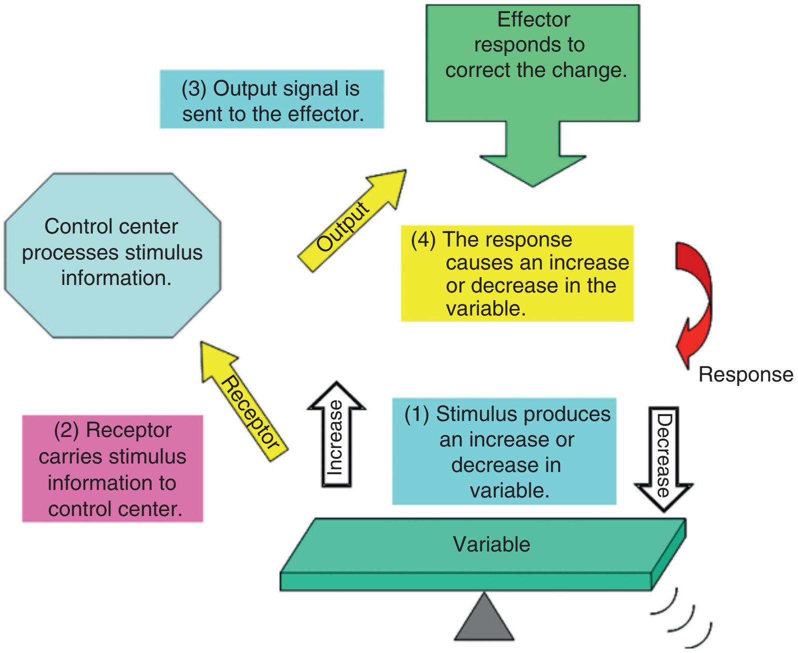

Fig. 1.4 Feedback systems. (1) A stimulus causes a change in a variable (i.e., plasma glucose, blood pressure, heart rate, etc.). (2) A receptor senses the change in the variable and sends that information to the control center. (3) The control center compares the level of the variable to a set point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

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 adrenal glands. This results in an increase in blood pressure and a change in blood flow such that there is an increase in skeletal muscle and a decrease in the digestive tract.

The regulated factor is the variable. The regulatory mechanisms involve a receptor, a control center, and an effector. The receptor (a modified neuron) senses a change in the environment, called a stimulus. In response to the stimulus, the receptor transmits an afferent signal to the control center. The control center has a set point, which defines the usual range of values for the variable. When the input signal is outside of the range of the set point, an appropriate response occurs to correct the variable value. An efferent signal from the control center travels to the effector. The effector induces a change in the controlled variable to bring it back within the range of 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 change that counteracts the stimulus (Fig. 1.5). This either reduces or eliminates the stimulus thereby reestablishing the variable near its set point and maintaining 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, for example, with sun exposure, temperature receptors in the skin and hypothalamus sense the increase 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.

Although 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.

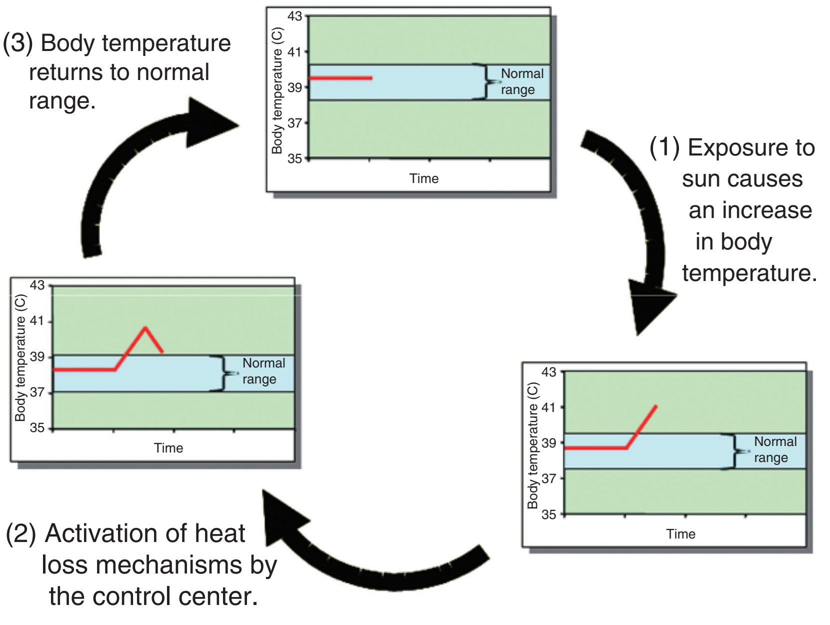

Fig. 1.5 Negative feedback systems. (1) A stimulus causes a change in a variable, in this example, an increase in body temperature. (2) Information regarding the increase in body temperature is carried to the control center, which activates appropriate heat loss mechanisms to decrease body temperature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

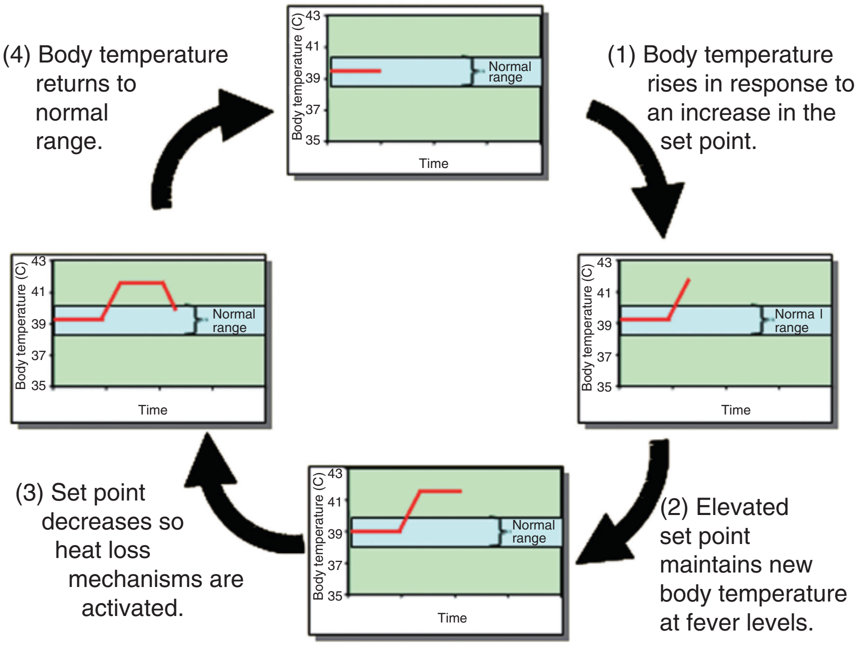

Fig. 1.6 Changes in the homeostatic set points. The set point for a variable can change. For example, the development of a fever involves a change in the body temperature set point. (1) The control center responds to an increase in the set point for body temperature caused by a pyrogen (i.e., something 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.

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 causes an augmentation of the stimulus, which further increases the response. Although 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. Although this is beneficial in preventing the loss of blood, if left unchecked, the clotting process would continue until all the blood in the body is clotted, resulting in death.

Birth is another classic example of a positive feedback system. Near the time of parturition, oxytocin along with prostaglandins initiates uterine contractions. The uterine contractions cause the hypothalamus of the mother to release more oxytocin, causing greater uterine contractions. This initiates a positive feedback loop to ensure the completion of parturition.

Anatomical Nomenclature

As with any field of science, anatomy has its own language. It is necessary to know this language to accurately describe structures and events. 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 describe an animal that is in the anatomical position. In the case of humans that are bipeds (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 quadrupeds (i.e., walk on four legs), the anatomical position entails standing on all four limbs.

Table 1.1 provides a listing of positional and directional terms. 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

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

halfway between the trunk and the hoof." With directional and positional terms, a better answer is "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. Although 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 consider 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. 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 a median, or midsagittal, plane. Any sagittal plane other than the midsagittal is called 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.

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.

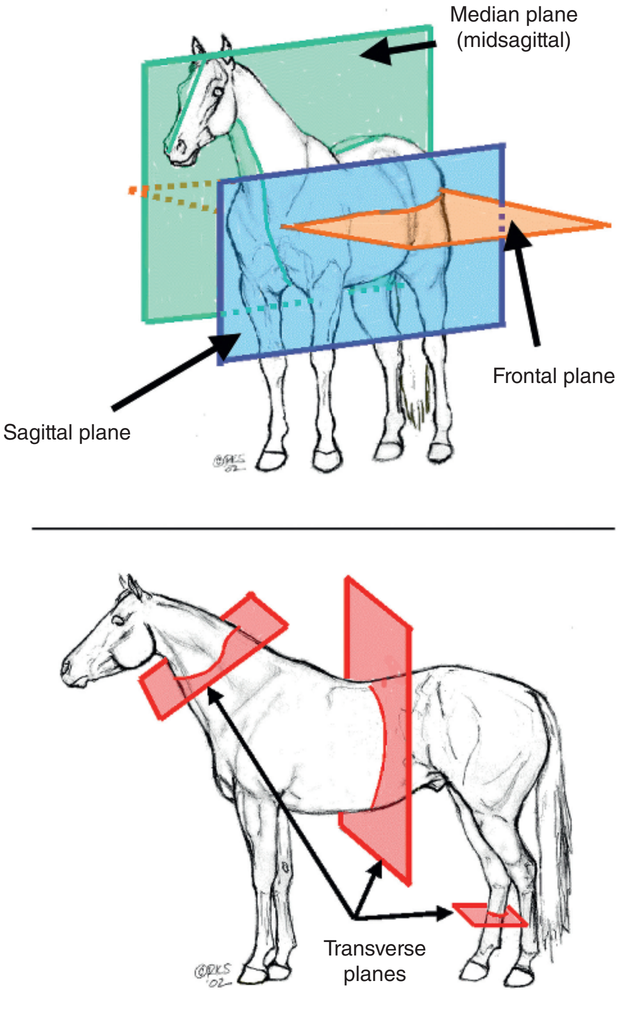

Fig. 1.7 Planes of the body. The three major planes (frontal, transverse, and sagittal) are shown.

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 the 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 the dorsal surface and at right angles to the median plane

Body Cavities and Membranes

A median view of an animal will reveal two cavities, the dorsal and the 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 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 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 location. 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.

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