V. The Respiratory System

V.1. Objectives

- state the function of each component of the respiratory system
- describe the air flow from the nose to the alveoli of the lungs
- dissect the structures and organs of the respiratory system, and identify them by name
- identify the parts of the larynx and its cartilages
- describe the anatomy of the lungs of different species
- understand the flow of air between the air sacs and lungs of the bird and their connection to the pneumatic bones
- understand the various methods of measuring lung volumes and capacities
- understand the concept of dead space

V.2. Introduction

The respiratory system's primary function is the transport of oxygen and carbon dioxide between the environment and the tissues. The respiratory system can be divided into two parts: the upper respiratory system and lower respiratory system. The structures of the upper respiratory system include the external nares, nasal cavity, sinuses, and larynx. The lower respiratory system includes the trachea, bronchi, bronchioles, and alveoli. The respiratory system performs ventilation and respiration. Ventilation is the process of breathing (also called pulmonary ventilation), which is the movement of gases in and out of the lungs. Respiration is a broader term that includes not only the act of ventilation but also the distribution of gases in the alveoli and the diffusion of oxygen into and of carbon dioxide out of the bloodstream. This exchange of gases in and out of the blood is called external respiration. Internal respiration is the exchange of gases between blood and tissues.

Ventilation

- Ventilation is the movement of gas into and out of the lung.
- Ventilation requires muscular energy.
- The respiratory muscles generate work to stretch the lung and overcome the frictional resistance to airflow provided by the airways (airway resistance).
- Lung elasticity results from tissue and surface tension forces.
- The lung is mechanically connected to the thoracic cage by the pleural liquid.

- Airflow is opposed by frictional resistance in the airways.
- Smooth muscle contraction affects the diameters of the trachea, bronchi, and bronchioles.
- Dynamic compression can narrow the airways and limit airflow.
- The distribution of air depends on the local mechanical properties of the lung.
- In some species, air travels between adjacent regions of lung through collateral pathways.

V.2. Anatomy of the respiratory system

The air enters the nasal cavity through the nares or nostrils. These openings vary in size and shape with each species. The horse's nostrils are large and easily dilated, whereas the pig's are small and rigid. The non-haired area of the nose is called the planum nasale (or planum nasolabiale in species with a large muzzle). The most rostral part of the nasal cavity is the nasal vestibule, which is the open chamber behind the nostrils that is lined with simple squamous epithelial cells.

The two nasal cavities, left and right, are separated rostrally by a cartilaginous septum. Each cavity is divided further by the nasal bone in the center and by the nasal turbinate bones projecting from the lateral wall of the nasal passage. The bony turbinates are scroll-like in appearance and are covered by nasal mucosa to form the nasal conchae. These effectively divide the fl owing air into channels: the ventral meatus, middle meatus, dorsal meatus, and common meatus. The mucosa is made up of pseudostratifi ed ciliated columnar epithelial cells, goblet cells, and nasal glands. These channels increase air turbulence and thereby warm, moisten, and filter air as it passes through.

The main sinuses are the maxillary and frontal sinuses, which are located within the bones for which they are named. Large animals also have a sphenoid sinus and a palatine sinus, except the horse, in which these two sinuses are fused into a sphenopalatine sinus. The cow and sheep have an additional sinus, the lacrimal sinus. These sinuses act as resonance chambers in phonation, and their mucosa, like that of the nasal cavity, warms and moistens the incoming air.

From the nasal cavity the air moves through the choanae (air passageway of the internal nares) and into the nasopharynx. On the dorsolateral wall of the nasopharynx are openings to the auditory or eustachian tubes. These act in pressure regulation with the middle ear, to which the tubes connect. (In the horse, each eustachian tube opens into a large ventral diverticulum within the nasopharynx known as the guttural pouch, which is located just lateral to the pharynx.) The nasopharynx is separated from the oropharynx by the soft palate. The position of the open epiglottis, either contacting the caudal edge of the soft palate or just beneath it, causes inhaled air to pass through the nasopharynx into the laryngopharynx (the area above the open epiglottis) and directly into the larynx.

The larynx is a hard tube made of cartilages. The thyroid cartilage is the large, ventral cartilage visible after removal of the ventral neck muscles. The cricoid cartilage is located caudal to the thyroid cartilage. This cartilage is shaped like a signet ring, with the small band located ventrally and an expanded portion located dorsally on both sides.

The cricothyroid ligament is the semi-transparent membrane in the space between the cricoid and thyroid cartilages. Make a median longitudinal incision through these two cartilages on the ventral ridge and through the basihyoid bone (the most ventral bone of the hyoid apparatus). The two pyramid-shaped arytenoid cartilages on the dorsal surface of the larynx, cranial to the cricoid cartilage.

The epiglottis is the most cranial cartilage of the larynx and can be seen at the base of the tongue during the dissection of the mouth. This pointed, leaf-like cartilage is attached ventrally to the thyroid cartilage.

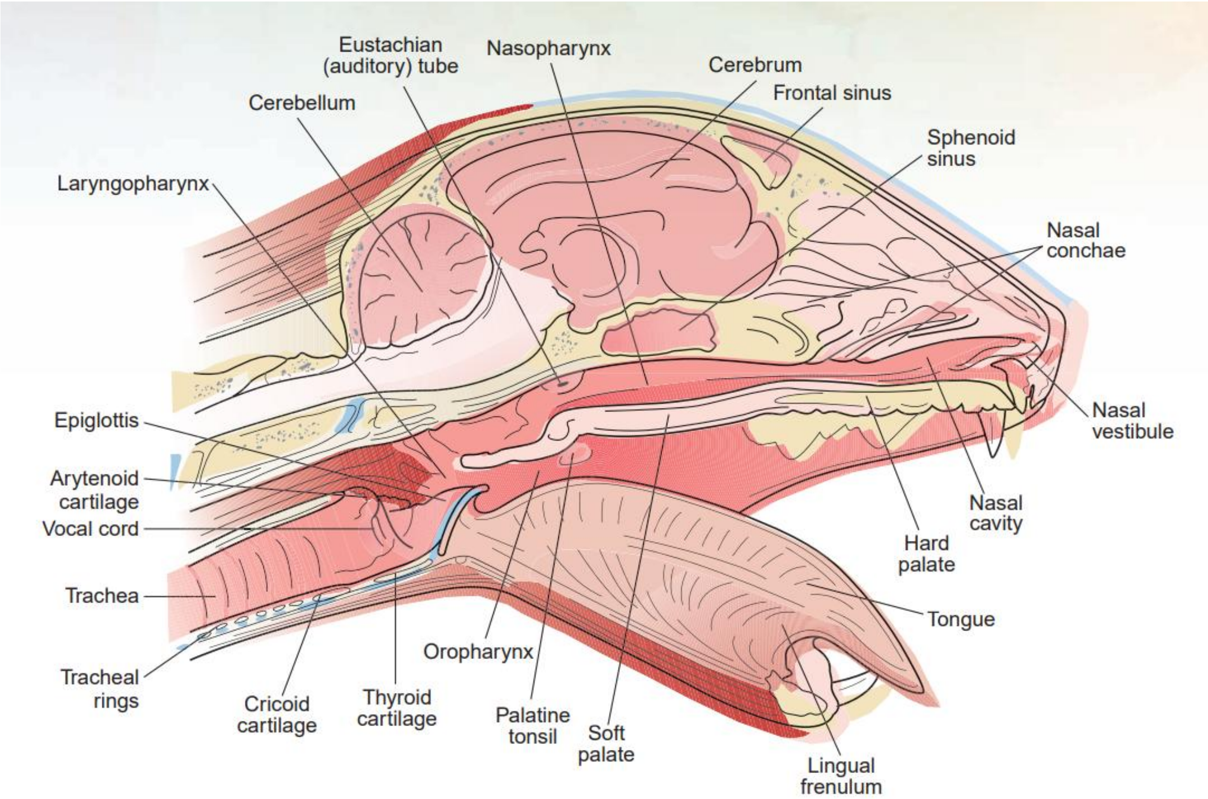

FIGURE 11.1: Sagittal view of the cat's head.

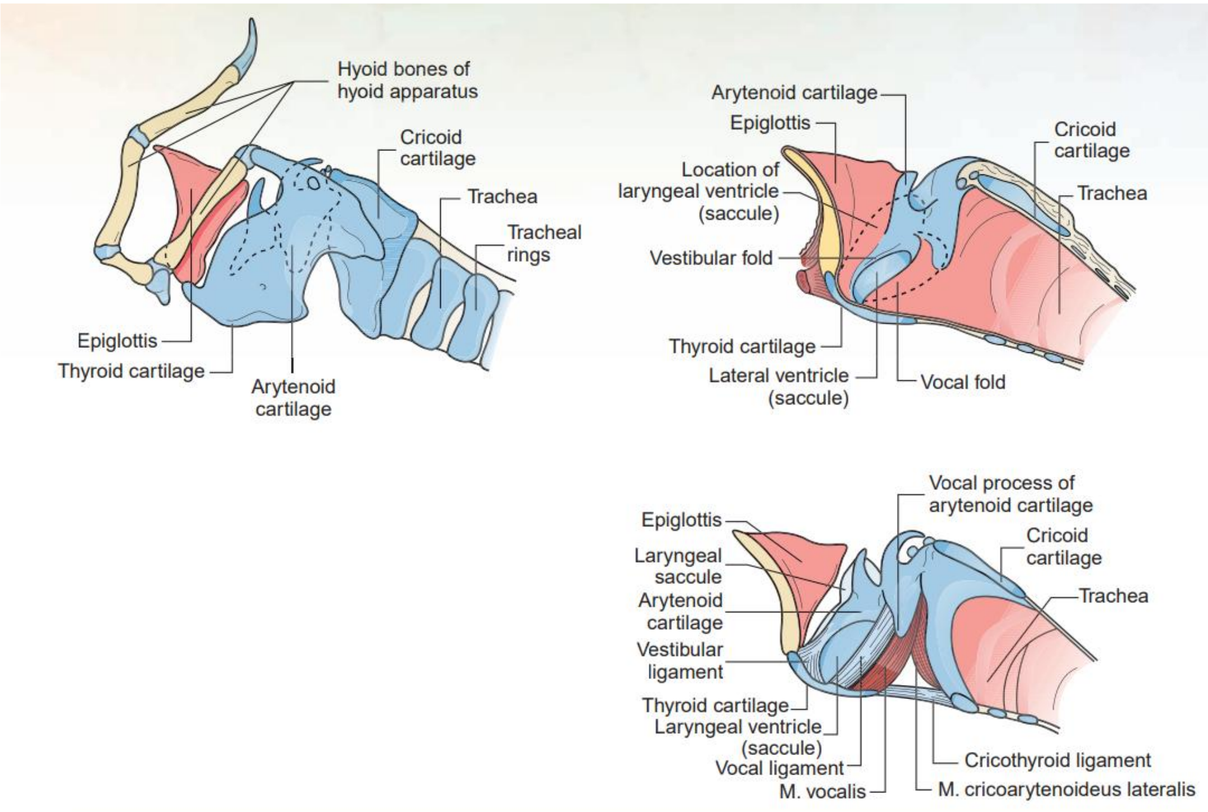

FIGURE 11.3: Laryngeal cartilages and the structure of the larynx (dog). A. Cartilaginous structures of the larynx and the hyoid apparatus. B. Structures of the larynx with mucosa attached. C. Structures of the larynx with mucosa removed.

The lungs are on either side of the thorax. Each lung is divided into lobes. There are four lobes on the right side: the cranial, middle, caudal, and accessory lobes; and there are two lobes on the left: the cranial and caudal lobes. Note in Figure that the horse has a single right and left lung lobe, and a smaller accessory lobe of the right lung. These lobes were formerly known as the apical (cranial), cardiac (middle), diaphragmatic (caudal), and intermediate (accessory) lobes.

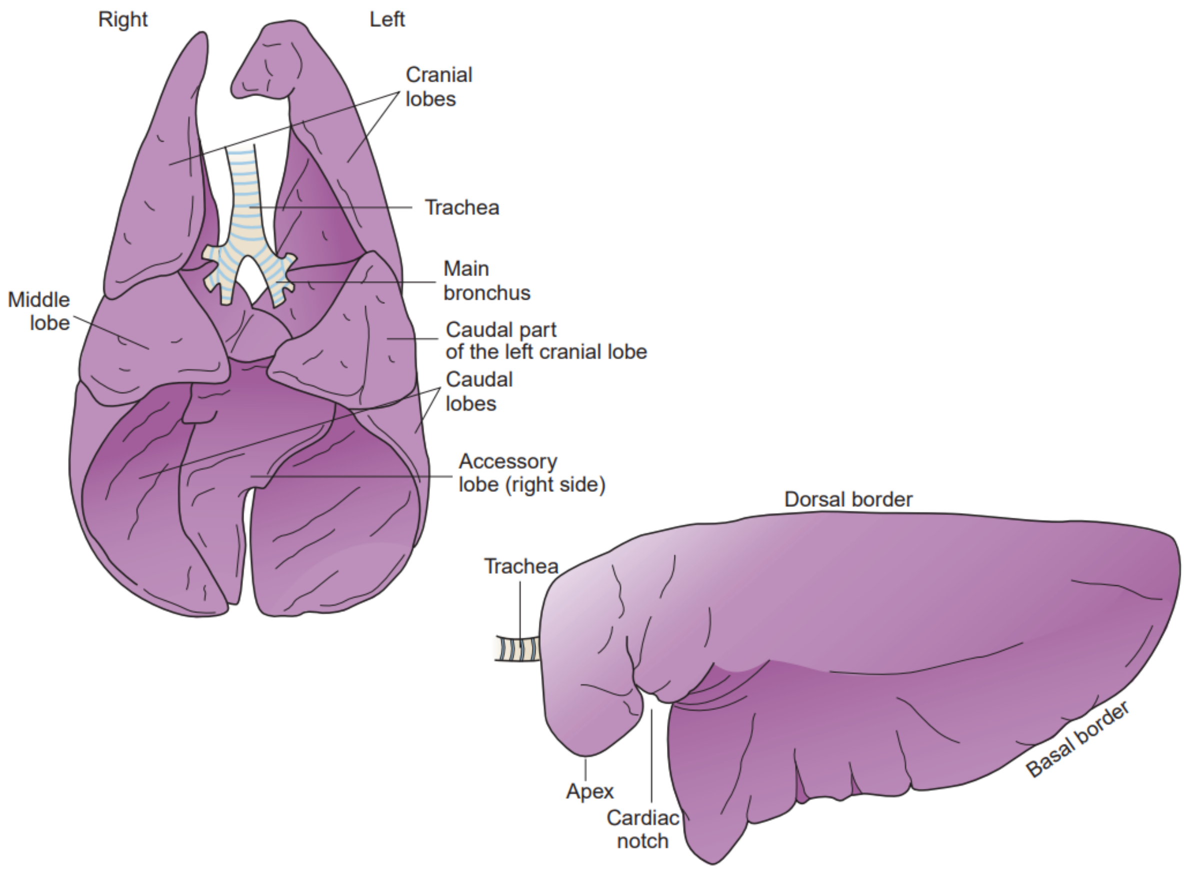

FIGURE 11.7: A. Lobes of the lung in a cat. B. Lobes of the lung in a horse.

Note that the lungs are attached to other structures in the thorax only by the root. The root of the lung is formed by the branching of the bronchi, the pulmonary artery and veins, the nerves, and the lymphatic vessels and lymph nodes, all of which are encircled by pleura.

As the main bronchus enters the lungs, it becomes a lobar bronchus, which is the tube that courses the entire distance down the lung lobe. The branches from this are the segmental bronchi. Segmental bronchi have less cartilage than the main and lobar bronchi. The branches off the segmental bronchi are the terminal bronchioles, which are too small to be dissected and look like the tissue of the lungs. The trachea and the bronchial tree down to the first 2/3 of the terminal bronchioles is lined with pseudostratified ciliated columnar epithelium. The last 1/3 is simple ciliated columnar epithelium. Branching off the terminal bronchioles are the respiratory units, each of which consists of a respiratory bronchiole, an alveolar duct, an alveolar sac, and alveoli (Figure 11.10). This is called a respiratory unit because all the structures contain alveoli, which are where external respiration occurs.

In the mid-cranial area of the thoracic cavity, where the cranial mediastinum is located, is a large, fluctuant-appearing gland called the thymus gland. This gland, divided into lobules, is large in young cats but smaller in older ones. Just dorsal to this gland, within the cranial mediastinum, are the mediastinal lymph nodes.

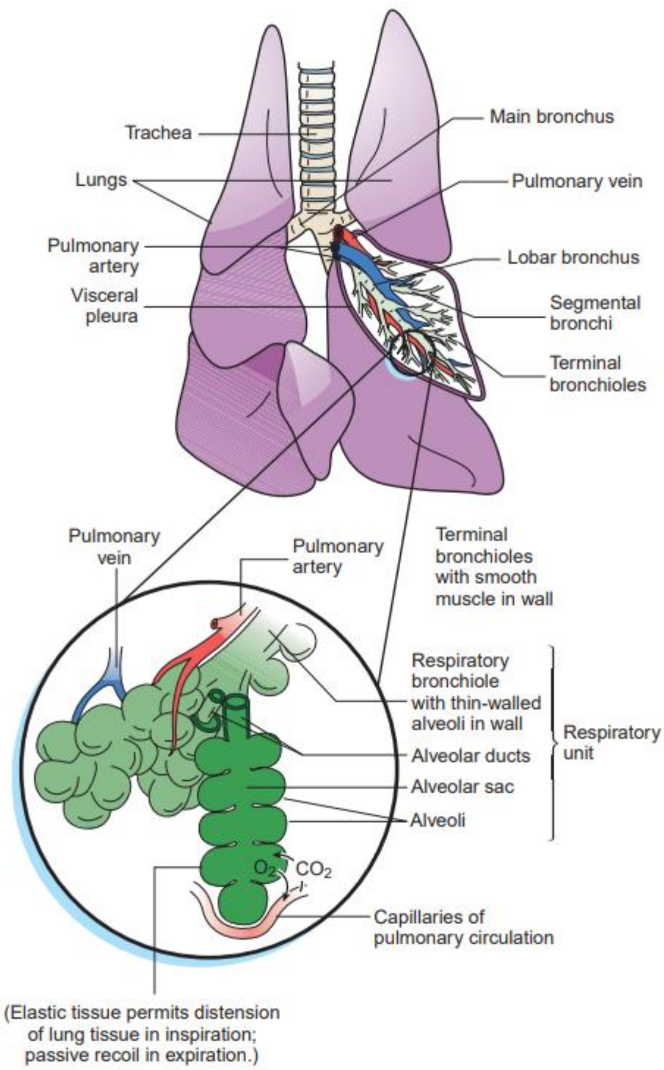

FIGURE 11.10: Bronchiolar system of the lungs (all species).

V.3. Respiratory function

The respiratory system provides oxygen (O2) to support tissue metabolism and removes carbon dioxide (CO2). Oxygen consumption and carbon dioxide production vary with the metabolic rate, which is dependent on the animal's level of activity. Basal metabolism, the metabolism of the resting animal, is a function of metabolic body weight ($M^{0.75}$). The consequence of this relationship is that smaller species consume more oxygen per kilo�gram of body weight than do larger species. For example, the 20-gram mouse consumes six times more oxygen per unit body mass than does a 70-kg pig. This difference is largely due to the metabolic requirements necessary to maintain constant body temperature. Because smaller species have a greater surface area to body weight ratio, they have a greater surface for heat loss and less heat storage capacity so they need higher basal metabolism to generate more heat.

When animals exercise, their muscles need more oxygen, which leads to an increase in oxygen consumption. Maximal oxygen consumption ($V\ O_2$ max) is directly related to the total mass of mitochondria within the skeletal muscles. Athletic species such as the horse and dog have greater mitochondrial density and therefore greater V O max2 than do less athletic species of similar body size such as the cow and goat. Gas exchange requirements vary with metabolism and may increase up to 30 times during strenuous exercise.

V.4. Lung Volumes and Capacities

- **Tidal volume (VT):** Volume of air moving in (or out) during normal breathing.
- **Inspiratory reserve volume:** Volume of air it is possible to inhale after a normal inspiration.
- **Expiratory reserve volume:** Volume of air it is possible to exhale after a normal expiration.
- **Residual volume:** Volume of air in the lungs, even after maximum expiration.
- **Vital capacity:** The total volume of air that can be exhaled after a maximum inspiration.
- **Functional residual capacity**: The sum of the expiratory reserve volume and the residual volume. Functional residual capacity equals the volume of gas left in the lungs at the end of a normal expiration, and this remaining gas will mix with the next

tidal volume. Functional residual capacity also shows that the alveoli do not fill with fresh air on each inspiration.

- **Dead space:** The space occupied by air at the end of an expiration. Dead space is also the volume of the respiratory system that takes no active role in external respiration; in other words, it is the volume of air that occupies the space between the nose and the respiratory unit. Only the respiratory unit has alveoli in which external respiration can occur. If an endotracheal tube is inserted and extends through the mouth, as in gas anesthesia, this added volume is added dead space.

V.5. Ventilation

Ventilation Is the Movement of Gas Into and Out of the Lung. The oxygen needs of metabolism require that an animal take a certain volume of air into its lungs, especially its alveoli, each minute. The total volume of air breathed per minute, also known as minute ventilation (V_E), is determined by the volume of each breath, known as the tidal volume (V_T), and the number of breaths per minute, known as respiratory frequency (f), as clarified next from the following equation:

$$V_E = V_T \times f$$

The increase in V_E, which must occur when an increase in metabolic rate demands more oxygen, can be brought about through an increase in V_T, f, or both.

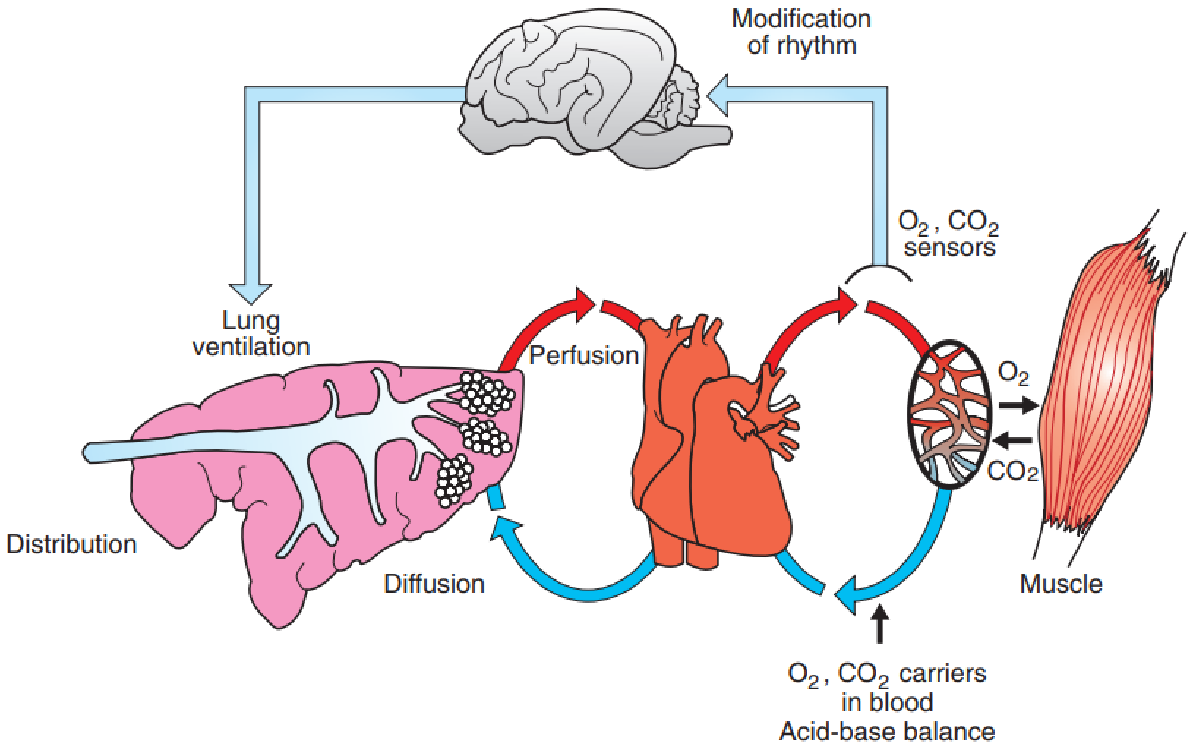

FIGURE 45-2 Diagrammatic representation of the processes involved in gas exchange. The lung is shown on the left, the heart in the center, and tissues on the right. The brain is shown at the top.

Air flows into the alveoli through the nares, nasal cavity, pharynx, larynx, trachea, bronchi, and bronchioles. These structures constitute the conducting airways. Because gas exchange does not occur in these pathways, they are also known as the anatomic dead-space (Figure 45-3). Dead-space can also occur within the alveoli. This alveolar dead-space is caused by alveoli that are poorly perfused with blood, so that gas exchange cannot occur optimally. Physiologic dead-space is the sum of the anatomic and the alveolar dead-space. Let us define the portion of each VT that enters the alveoli as V_A and the part that enters the dead-space as V_D. Then:

$$VT = VA + VD$$

If each side of this equation is multiplied by respiratory frequency (f) as follows:

$$VT \times f = (V_A \times f) + (V_D \times f)$$

The result is: $V_E = V_A + V_D$

VI. The endocrine system

VI.1. Objectives

- Identify and name the major endocrine organs in the body and the brain
- List the hormones produced by the hypothalamus and the pituitary gland, and the target organs of each
- Understand the feedback mechanism that controls the release of these hormones
- Understand the basic functions of the hormones produced by endocrine glands

VI.2. Introduction

The endocrine system is system of glands that produce hormones, which are chemical messengers in the body. These hormones are released directly into the blood and transported throughout the body. Whereas the nervous system is able to effect rapid changes in the body (via electrochemical impulses generated by neurons), hormones tend to produce slower changes. Although they are released into the bloodstream, specific hormones affect the biochemical activity of only one or a few specific organs. An organ that responds to a particular hormone is referred to as the hormone's target organ. The target tissue's response seems to depend on the hormone molecule's ability to bind with specific receptors (proteins) on the cells' plasma membranes or within the cells. Hormones are most often either steroid- or amino-acid-based molecules. When the hormone binds with the target organ's cells, it stimulates changes in the organ's metabolic activity. For example, thyroid-stimulating hormone causes an increase in the metabolic activity of thyroid cells, which increases production of thyroid hormones. An increase in thyroid hormones affects many cells of the body by stimulating their metabolic activity. Some endocrine glands produce only hormones; others produce both hormones and certain cell types, such as reproductive cells. Examples of the former are the anterior pituitary, thyroid, parathyroid, and adrenal glands. Examples of the latter are the testes and ovaries. Both types of glands are derived from epithelial tissue during development, but the endocrine (or ductless) glands secrete their products into the blood or lymph. The exocrine glands secrete their products onto an epithelial surface, whereas endocrine glands secrete directly into the bloodstream. The pancreas has both endocrine and exocrine glandular tissue

VI.3. Anatomy and Physiology of the Hypothalamus and Pituitary Gland

The pituitary gland, or hypophysis, is attached to the hypothalamus at the base of the brain by a slender stalk called the infundibulum. The pituitary gland consists of two major functional areas: the anterior pituitary, or adenohypophysis, and the posterior pituitary, or neurohypophysis. The adenohypophysis consists of three portions: the pars distalis, pars intermedia, and pars tuberalis. The neurohypophysis contains the pars nervosa and is directly connected to the hypothalamus by the infundibulum. The shape of the pituitary gland and the degree of development of its relative parts vary in domestic animals (Figure 13.1). The hypothalamus is an important regulatory center for the nervous system; it regulates body temperature, thirst, hunger, sexual behavior, and such reactions as fear and rage. Despite its many functions, the hypothalamus is quite small. It consists of the optic chiasm, infundibulum, tuber cinereum, Mammillary body, and hypophysis (Figures 13.2 and 13.3). The hypothalamus is also a crucial regulator of the endocrine system and pituitary gland. The hormones produced by the neurons in the ventral hypothalamus are of two types: releasing hormones, which stimulate specific cells of the anterior pituitary to produce certain hormones, and inhibitory hormones, which have an inhibitory effect and suppress production. Table 13.1 lists the hormones produced by the hypothalamus on the left, and hormones of the anterior pituitary that are affected are listed on the right. Two other hormones also are produced by the hypothalamus: antidiuretic hormone (ADH) and oxytocin. ADH is produced primarily in the supraoptic nuclei, and oxytocin primarily in the paraventricular nuclei. These are special neurosecretory neurons that allow their product to slide down an axon into the posterior pituitary gland, or neurohypophysis, for release into the blood (Figure 13.4).

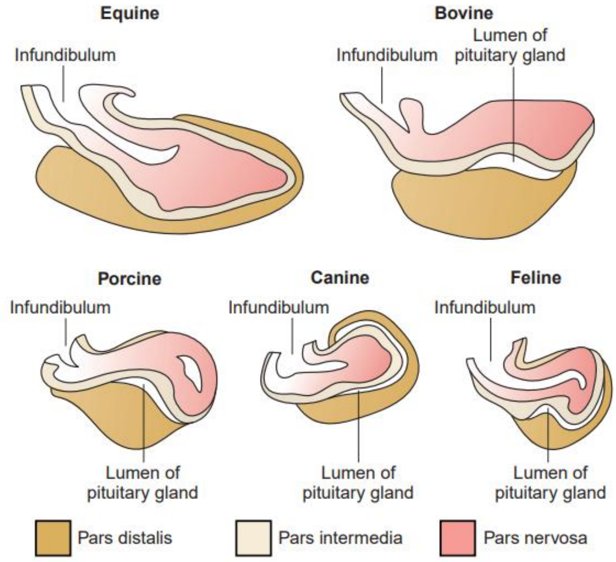

FIGURE 13.1: Comparative pituitary glands of various species.

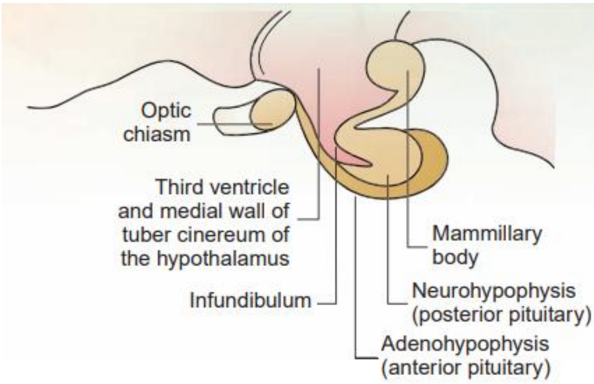

FIGURE 13.2: The hypothalamus and pituitary gland.

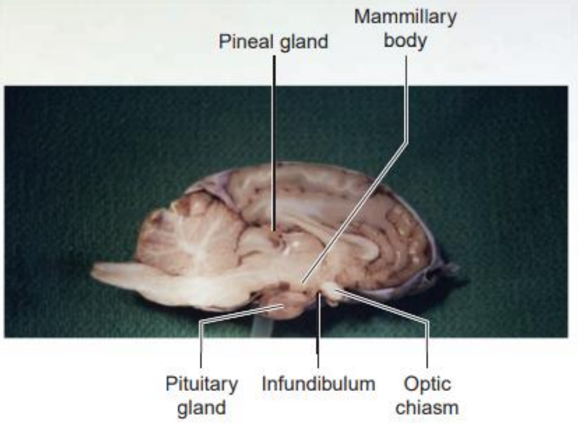

FIGURE 13.3: Sagittal section of the sheep brain showing the endocrine structures.

TABLE 13.1: Hormones of the Hypothalamus and Adenohypophysis

Releasing and inhibiting hormones	Anterior pituitary hormones affected
Somatotropin-releasing hormone (STH-RH)	Somatotropic hormone
Somatotropin releasing-inhibiting hormone (STH-RIH)	Somatotropic hormone
Thyrotropin-releasing hormone (TRH)	Thyroid-stimulating hormone
Corticotropin-releasing hormone (CRH)	Adrenocorticotropic hormone
Prolactin-releasing hormone (PRH)	Prolactin
Prolactin-inhibiting hormone (PIH)	Prolactin
Gonadotropin-releasing hormone (GnRH)	Follicle-stimulating hormone and luteinizing hormone

The releasing and inhibitory hormones produced in the hypothalamus are delivered to the anterior pituitary via the hypophyseal portal system. The capillaries in the ventral hypothalamus pick up these hormones and transfer them via the hypophyseal portal veins to the secretory cells of the adenohypophysis (see Figure 13.4).

The adenohypophysis is the glandular part of the pituitary gland (adeno means "gland"), and it produces the tropic hormones. The tropic hormones (see Table 13.1) stimulate target organs (which are also endocrine glands) to secrete their hormones. The hormones of the target organ then exert their influence on other body organs and tissues. There are seven known hormones produced by the anterior pituitary:

- **Somatotropic hormone (STH):** Also known as growth hormone (GH), STH is a general metabolic hormone that plays a role in determining body growth and size. However, it also affects many tissues of the body as it regulates metabolism of proteins, carbohydrates, and lipids. It acts as an anabolic hormone in its effect on the metabolism of body proteins; in other words, it stimulates formation and buildup of tissues, and thus is an important hormone in repair and regeneration.
- **Thyroid-stimulating hormone (TSH):** Influences growth and activity of the thyroid gland. Increasing TSH increases production of the thyroid hormones.
- **Adrenocorticotropic hormone (ACTH):** Regulates the endocrine activity of the adrenal cortex, the outer part of the adrenal gland. Increasing ACTH increases production of glucocorticoid hormones by the adrenal gland.
- **Follicle-stimulating hormone (FSH):** Stimulates follicular development in the female and spermatogenesis in the male.
- **Luteinizing hormone (LH):** Stimulates follicular rupture and formation of the corpus luteum in the female, and testosterone production in the male. In the male, it is called interstitial cell stimulating hormone (ICSH).
- **Prolactin:** Stimulates milk production at parturition and replenishment of milk during lactation. It may also stimulate testosterone production in males
- **Melanocyte-stimulating hormone (MSH):** Increases skin pigmentation by stimulating dispersion of melanin granules by melanocytes. This effect is readily demonstrated in lower vertebrates, such as amphibians and fish. Other actions of this hormone are not completely understood as yet.

Two hormones are secreted into the bloodstream from the neurohypophyis:

- **Antidiuretic hormone (ADH):** Studied in the last chapter, this hormone can be considered by its action as a water resorption hormone.
- **Oxytocin:** Stimulates uterine contractions during birth and milk let-down in the lactating mother.

VI.4. Physiology of the Glands of the Endocrine System

The hormones produced by target organs have a feedback effect on the hypothalamus and pituitary gland; as they are produced, their serum levels are detected by the hypothalamus, and secretion of the releasing factors is diminished. As levels drop, secretion of releasing factors increases. In this way, a constant level is maintained in the blood. To review, target organs regulated by the hormones of the adenohypophysis are the adrenal glands, thyroid glands, parathyroid glands, and reproductive organs.

VI.4.1. Adrenal Glands

The adrenal glands, like many organs, have an outer area called the cortex and a central area called the medulla. The adrenal cortex is divided into three zones:

- The zona glomerulosa is the outer layer (under the capsule) that produces mineralocorticoids. Aldosterone constitutes 95% of the hormones produced by the zona glomerulosa and is responsible for sodium reabsorption by the kidneys.
- The zona fasciculata is the middle layer and is the widest; it produces glucocorticoids.
- The zona reticularis is the inner layer and produces a small amount of weak androgens, which are steroid hormones that have a masculinizing effect. The major androgen secreted by the adre�nal gland is dehydroepiandrosterone (DHEA). This hormone has a minimal effect in males, but in females it contributes to libido.

The glucocorticoids produced are steroid-based molecules. They are cortisol (hydrocortisone), corticosterone, and cortisone. Of these three, cortisol is the most abundant and is responsible for approximately 95% of glucocorticoid activity. The metabolism of glucocorticoids is catabolic; that is, tissues are broken down to produce products needed for metabolism. The glucocorticoids’ metabolic activities include:

- increasing gluconeogenesis in liver
- decreasing peripheral glucose use
- increasing proteolysis in skeletal muscle
- increasing circulating levels of amino acids
- increasing mobilization of free fatty acids
- producing an anti-infl ammatory effect
- producing an anti-allergic effect
- decreasing the immune system’s functionality

The adrenal medulla is not considered glandular tissue; instead it is modifi ed sympathetic nervous tissue. Its products are norepinephrine, which is also released at post-ganglionic, sympathetic nerve endings, and epinephrine (adrenalin), which constitutes approximately 80% of the total secretion by this gland. Both these hormones are sympathomimetic; that is, their effects mimic the effects of the sympathetic division of the autonomic nervous system. When released into the blood, these two chemicals:

- stimulate an increase in heart rate and force of contraction
- serve as vasoconstrictors that produce increased peripheral resistance
- increase blood pressure
- counteract the depressing action of insulin on blood sugar, thereby raising blood sugar levels
- stimulate ACTH release
- stimulate glucagon to initiate glycogenolysis in the liver
- stimulate the breakdown of fats for energy

VI.4.2. The Thyroid Gland

The thyroid gland produces the hormones triiodothyronine (T3), tetraiodothyronine (T4), and thyrocalcitonin (TCT). Of T3 and T4, T4 is the most prevalent in farm animals, dogs, and cats. In general, T3 and T4 are the hormones that regulate (1) basal metabolic rate and oxygen use, (2) cellular metabolism, and (3) normal growth and tissue differentiation. In addition, as production of T3 and T4 rises, so do the following metabolic activities:

- glucose absorption and utilization

- cholesterol synthesis (but under deficiency conditions, cholesterol levels rise because of decreased elimination via the bile)
- potentiated effects of norepinephrine

The metabolism of thyrocalcitonin will be discussed with the parathyroid glands because its metabolic activity is associated with calcium and phosphorus balance in the body.

VI.4.3. Parathyroid Glands

The parathyroid glands are small nodules within or near the thyroid glands, usually two on each side. One is located external to and the other internal to the thyroid gland. They produce parathyroid hormone (PTH), which controls calcium levels in the blood, and thus phosphorus levels. PTH acts to increase calcium mobilization from bone, calcium absorption from the intestines, and calcium resorption from the kidneys.

A decreased PTH level causes decreased blood calcium levels, blood phosphorus levels, and urine phosphorus levels. A pathologic decrease in blood calcium levels causes tremors, muscle twitches, tetany, and convulsions. This condition could be caused by loss of calcium from the blood due to increased demand from the mammary glands in a period of increased milk production. If sufficient PTH is not available for release, calcium absorption from the intestinal tract cannot keep up with the demand. In dogs this condition is called eclampsia, or hypocalcemic tetany.

As previously mentioned, the hormone thyrocalcitonin (TCT) is produced by the thyroid gland. It keeps calcium in the bones by blocking reabsorption, and it moves calcium from blood back into the bone. TCT needs vitamin D as a coenzyme to work, and there is a relationship between PTH and TCT: If blood calcium levels are high, TCT is released; if blood calcium levels are low, PTH is released.

VI.4.3. The Pancreas

The pancreas's endocrine activity is not controlled by pituitary hormones, and this organ has both endocrine and exocrine activity. The exocrine portion of the pancreas secretes digestive enzymes into the duodenum. Histologically, the endocrine portion of the pancreas is composed of numerous islands of cells, called pancreatic islet cells (or islets of Langerhans), scattered throughout its tissue. The islets are composed of three types of cells:

alpha cells, beta cells, and delta cells. Beta cells produce insulin; alpha cells produce glucagon; and delta cells secrete soma�tostatin, gastrin, and a vasoactive intestinal peptide. Insulin has the following anabolic effects:

- facilitates transfer of glucose into cells (hypoglycemic effect)
- once inside a cell, causes glucose to be used more rapidly
- enhances glycogen formation
- increases glucokinase (which stimulates glucose to become glucose-6-phosphate)
- increases amino acid uptake in skeletal muscle

The primary effect of insulin is to facilitate transfer of glucose into cells. However, during exercise cells do not need insulin for glucose to enter. This fact has a practical application when considering a dog with diabetes mellitus. A consistent amount of daily exercise should reduce the quantity of insulin required daily.

Glucagon has the following effects:

- Increases glyconeogenesis from glucose in the liver
- Increase gluconeogenesis from amino acids and lactic acid (via pyruvic acid) in the liver
- Increases insulin secretion
- When given intravenously, relaxes smooth muscle

The hormones of the reproductive glands will be discussed in the next chapter. In the exercises in this chapter, the important structures are listed in colored bold print. If a structure is mentioned prior to its dissection, it is italicized. Structures discussed prior to dissection may also be in bold print for special emphasis.