Respiratory System 18

Objective A To define *respiration.*

All cells require a continuous supply of oxygen (O_2) and must continuously eliminate a metabolic waste product, carbon dioxide (CO_2). On the macroscopic level, the term *respiration* simply means ventilation, or "breathing." On the cellular level, it refers to the processes by which cells utilize O_2, produce CO_2, and convert energy into useful forms.

18.1 Distinguish between external *respiration, internal respiration,* and *cellular respiration.*

External respiration is the process by which gases are exchanged between the blood and the air. **Internal respiration** is the process by which gases are exchanged between the blood and the cells. **Cellular respiration** is the process by which cells use O_2 for metabolism and give off CO_2 as a waste.

Objective B To identify the *basic components of the respiratory system.*

The major passages of the respiratory system are the **nasal cavity, pharynx, larynx,** and **trachea** (fig. 18.1). Within the **lungs**, the trachea branches into **bronchi, bronchioles,** and finally, **pulmonary alveoli** (see fig. 18.6).

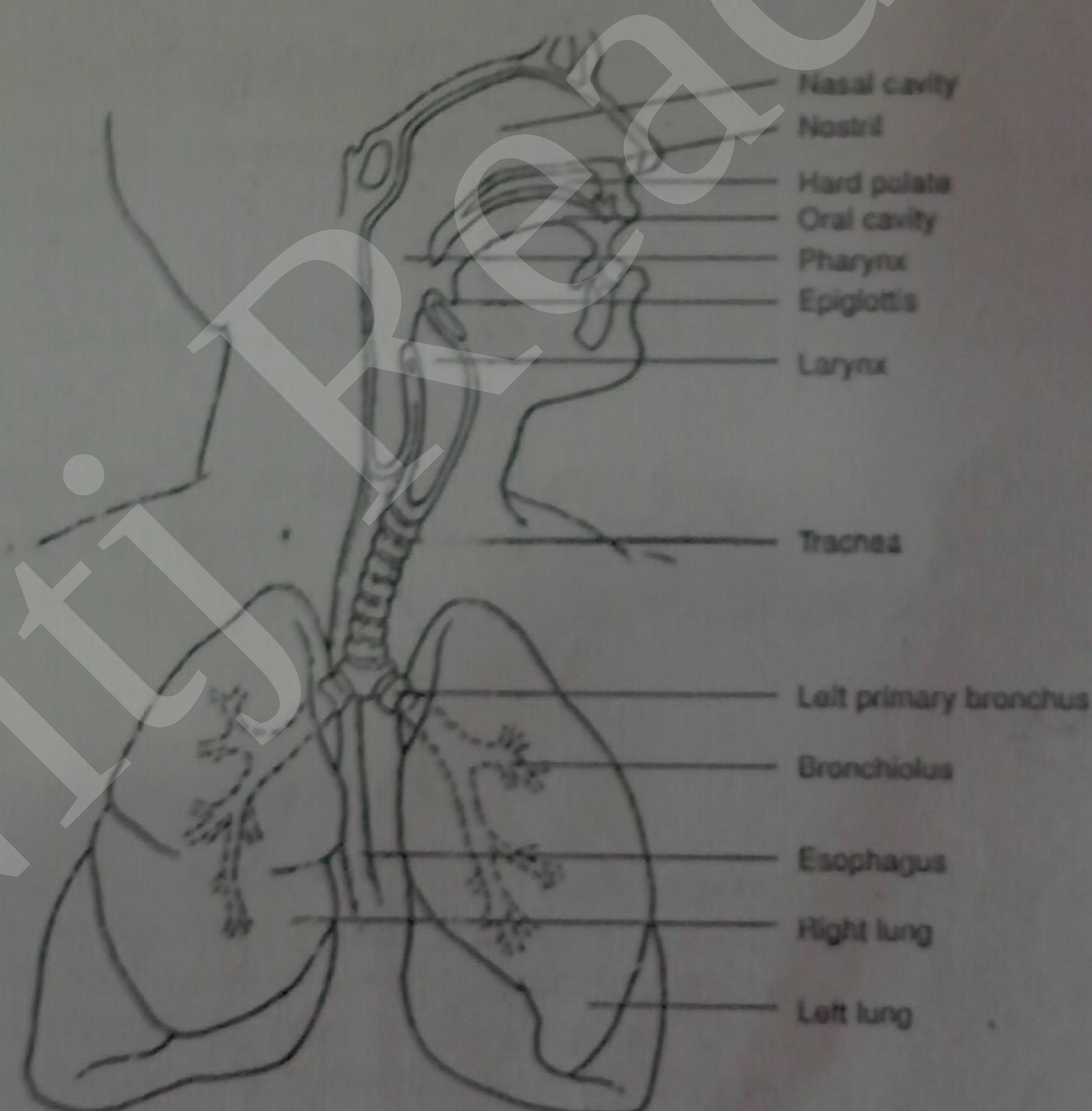

Figure 18.1 The respiratory system.

18.2 Distinguish between the conducting division and the respiratory division of the respiratory system.

The **conducting division** includes all cavities and structures that transport gases to and from the microscopic air pockets (pulmonary alveoli) in the lungs. The pulmonary alveoli constitute the **respiratory division**.

18.3 What physical requirements must be satisfied for the respiratory system to function effectively?

1. The membranes through which gases are exchanged with the circulatory system must be thin and differentially permeable so that diffusion can occur easily.
2. These membranes must be kept moist so that O_2 and CO_2 can be dissolved.
3. A rich blood supply must be present.
4. The surfaces for gas exchange must be located deep in the body so that the incoming air can be sufficiently warmed, moistened, and filtered.
5. There must be an effective pumping mechanism to constantly replenish the air.

Objective C To list the *functions of the respiratory system.*

1. *Gaseous exchange* for the cellular respiratory process
2. *Sound production* (vocalization) as expired air passes over the vocal cords
3. Assistance in *abdominal compression* during micturition (urination), defecation (passing of the feces), and parturition (childbirth)
4. *Coughing* and *sneezing* (self-cleaning reflexes)

18.4 What are the two phases of breathing?

Breathing, or pulmonary ventilation, consists of an **inspiration** (*inhalation*) **phase** and an **expiration** (*exhalation*) **phase.**

Objective D To describe the *nose, nasal cavity,* and *paranasal sinuses* as respiratory structures.

The **nose** includes an external portion that juts out from the face, and an internal **nasal cavity** for the passage of air. The **paranasal sinuses** (see problem 6.16) help, in a small way, to warm and moisten inspired air.

18.5 Describe the anatomy of the nasal cavity.

The **nasal cavity** is divided into two lateral halves, each referred to as a **nasal fossa,** by the **nasal septum.** The **vestibule** is the anterior expanded portion of a nasal fossa. In the lateral walls of either fossa are three shell-like concavities—the **superior, middle,** and **inferior conchae** (fig. 18.2). Air passageways, or **meatuses,** connect the conchae. The **nostrils** (*external nares*) open anteriorly into the nasal cavity, and the **choanae** (*posterior nares*) communicate posteriorly with the **nasopharynx.**

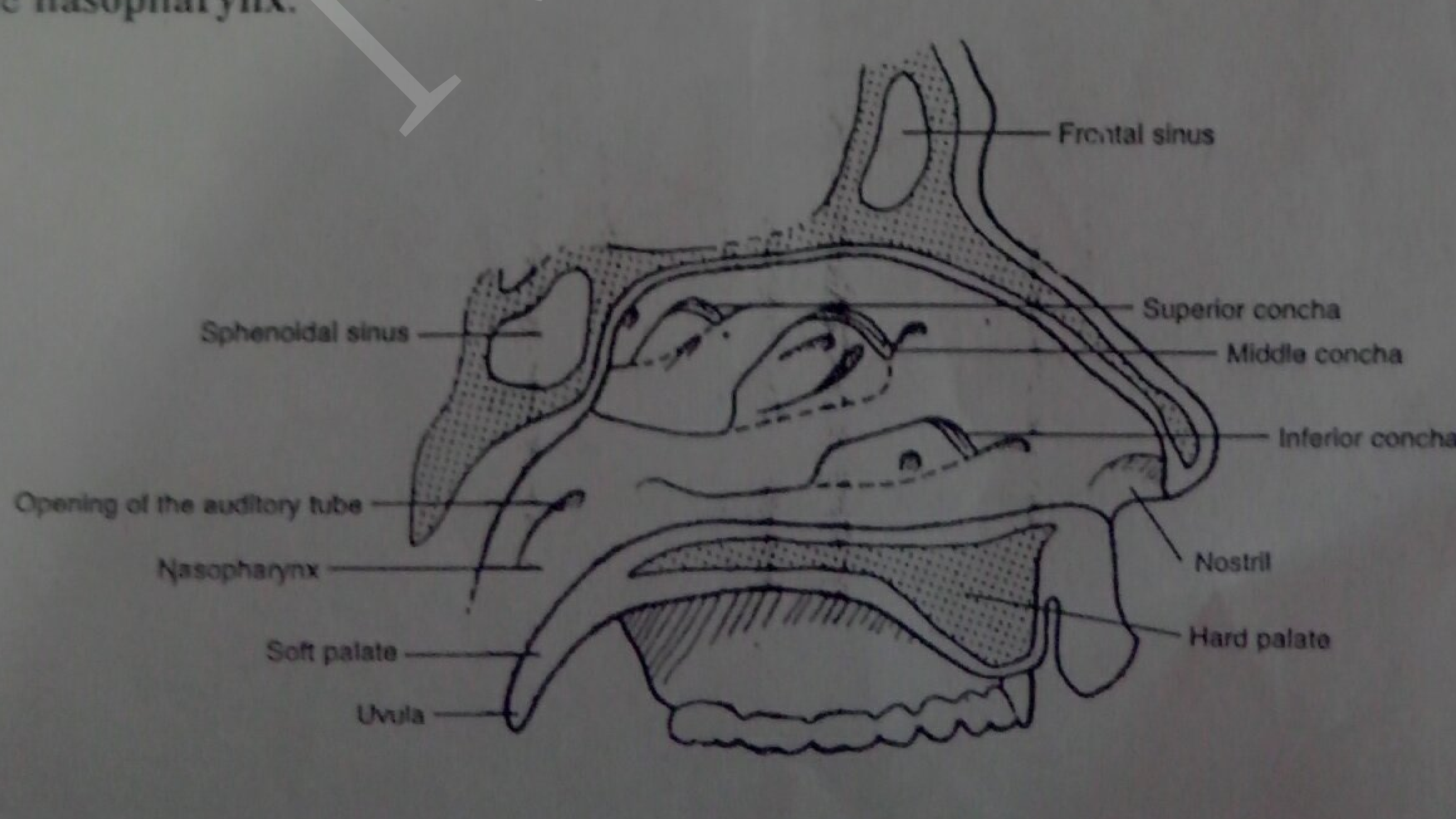

Figure 18.2 The nasal cavity and surrounding structures.

18.6 What types of tissues line the nasal cavity?

The vestibules are lined with *nonkeratinized stratified squamous epithelium* (see table 4.2); this epithelium divides rapidly and supports protective nasal hairs, or *vibrissae*. The conchae of the nasal fossae are lined with *pseudostratified ciliated columnar epithelium* (table 4.1), which secretes mucus to trap dust, pollen, smoke, and other inspired airborne particles. Specialized columnar epithelium, called *olfactory epithelium*, lines the upper medial portion of the nasal cavity, where it responds to odors.

18.7 Why are nosebleeds common?

The nasal epithelia are extensive and highly vascular, with the capillaries located close to the surface. This makes us susceptible to *epistaxes* (nosebleeds).

Objective E To describe the regions of the *pharynx*.

survey

The *pharynx* is divided on the basis of location and function into a **nasopharynx**, an **oropharynx**, and a **laryngopharynx**. The *auditory* (eustachian) *canals*, *uvula*, and *pharyngeal tonsils* are in the nasopharynx; the *palatine* and *lingual tonsils* are in the oropharynx (fig. 18.3). The oropharynx and laryngopharynx have respiratory and digestive functions, while the nasopharynx serves only the respiratory system.

18.8 How does the uvula serve both the respiratory and digestive systems?

The pendulous **uvula** hangs from the middle of the lower border of the soft palate. During swallowing, the soft palate and uvula are elevated, closing off the nasal cavity so that food or fluid cannot enter.

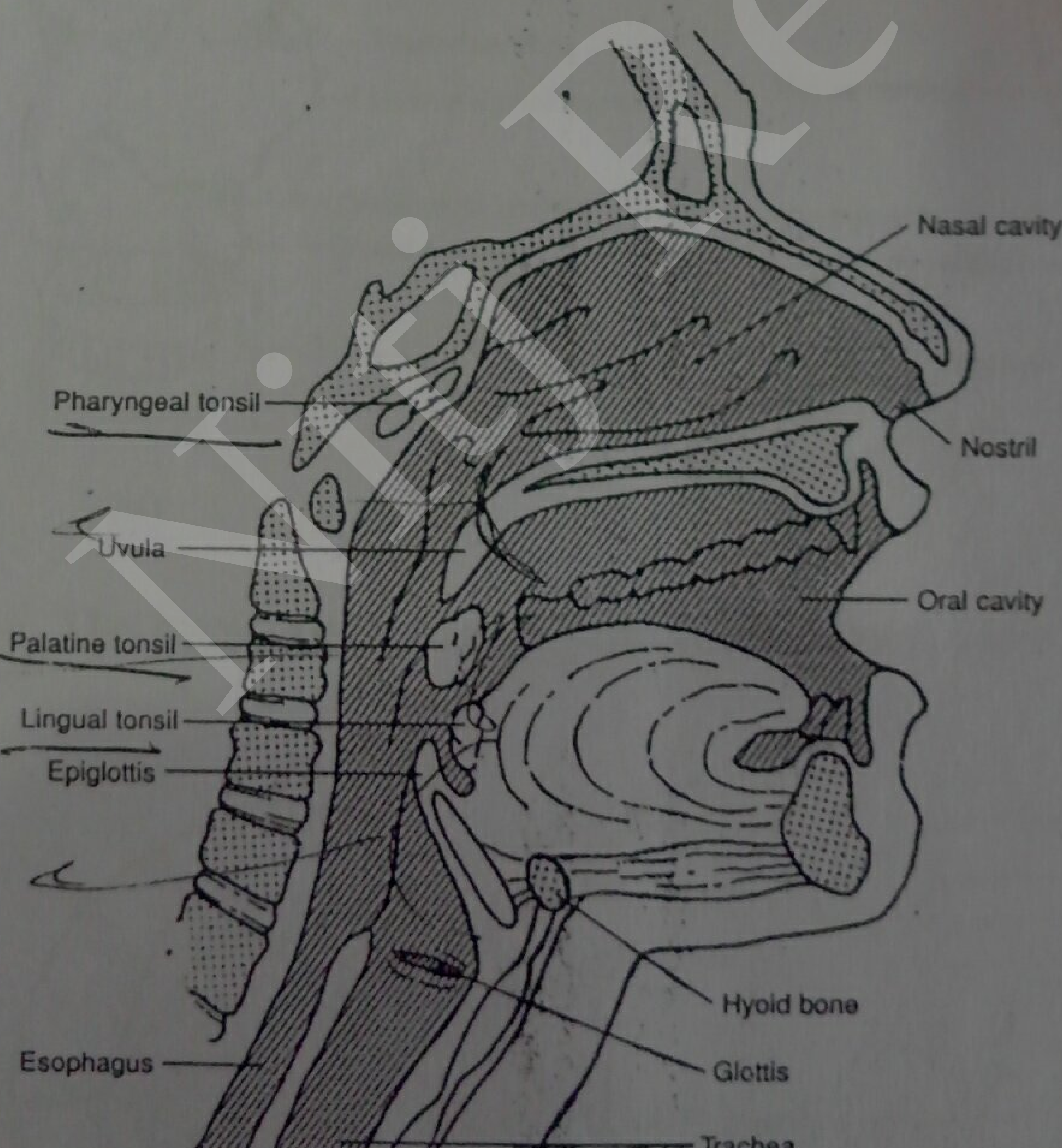

Figure 18.3 The nasal and oral cavities.

Objective F To identify the anatomical structures of the *larynx* associated with sound production and breathing.

The **larynx** (*voice box*) forms the entrance into the trachea. A primary function of the larynx is to prevent food or fluid from entering the trachea and lungs during swallowing, while permitting the passage of air into the trachea at other times. A secondary function is to produce sound vibrations.

18.9 Which cartilages of the larynx are paired and which are unpaired? Which cartilage is the largest and most prominent?

The *larynx* is a roughly triangular box composed of nine ~~hyaline~~ cartilages; three are large single structures and six are smaller paired structures (fig. 18.4). The **anterior thyroid cartilage** ("Adam's apple") is the largest. The spoon-shaped **epiglottis** has a cartilaginous framework. The lower portion of the larynx is formed by the ring-shaped **cricoid cartilage.** The three paired cartilages are the **arytenoid cartilages,** which support the vocal cords, and the **cuneiform** and **corniculate cartilages,** which aid the arytenoid cartilages. The **glottis** is the opening into the larynx (see fig. 18.5).

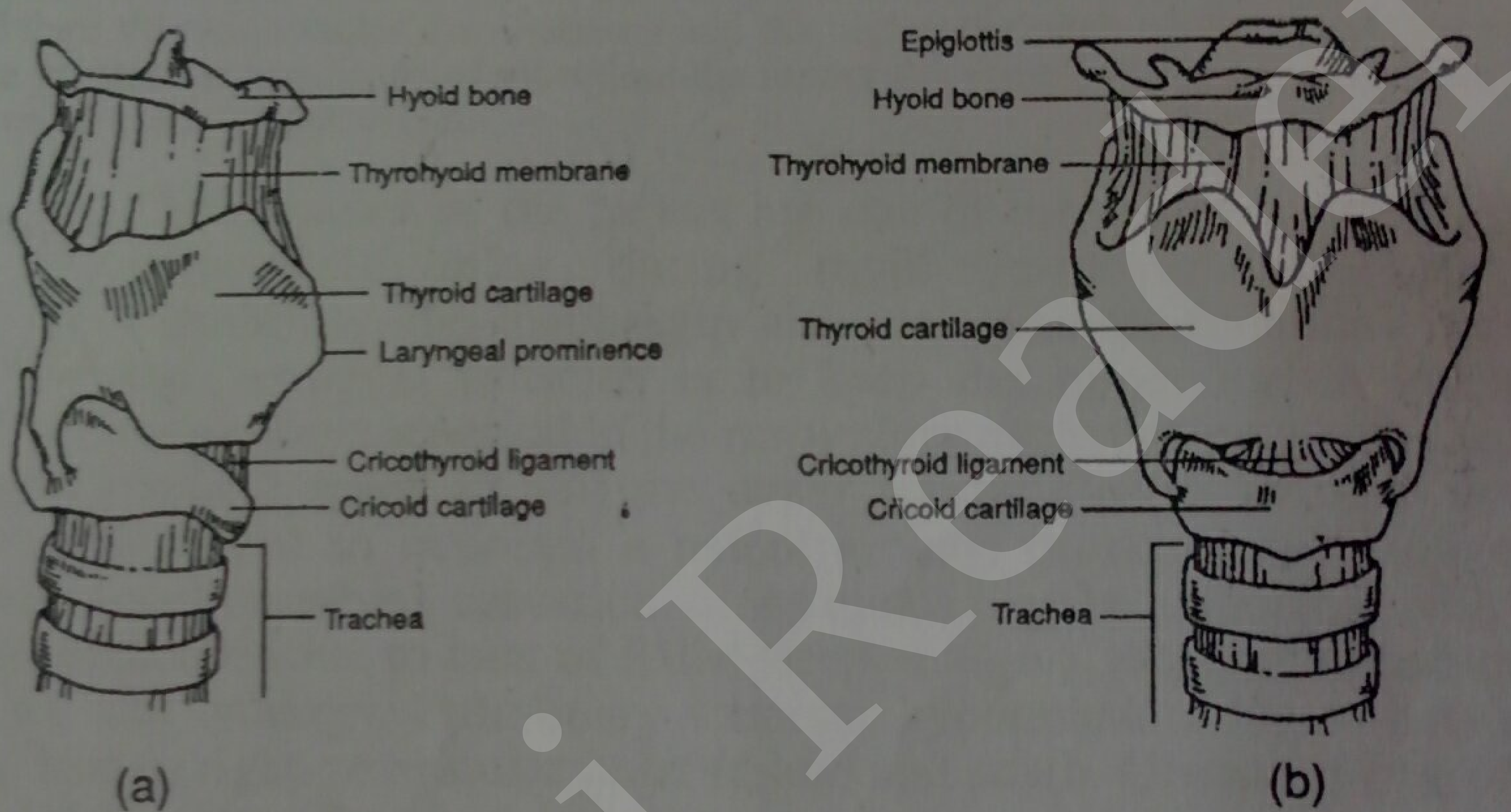

Figure 18.4 The hyoid bone and larynx. (*a*) A lateral view and (*b*) an anterior view.

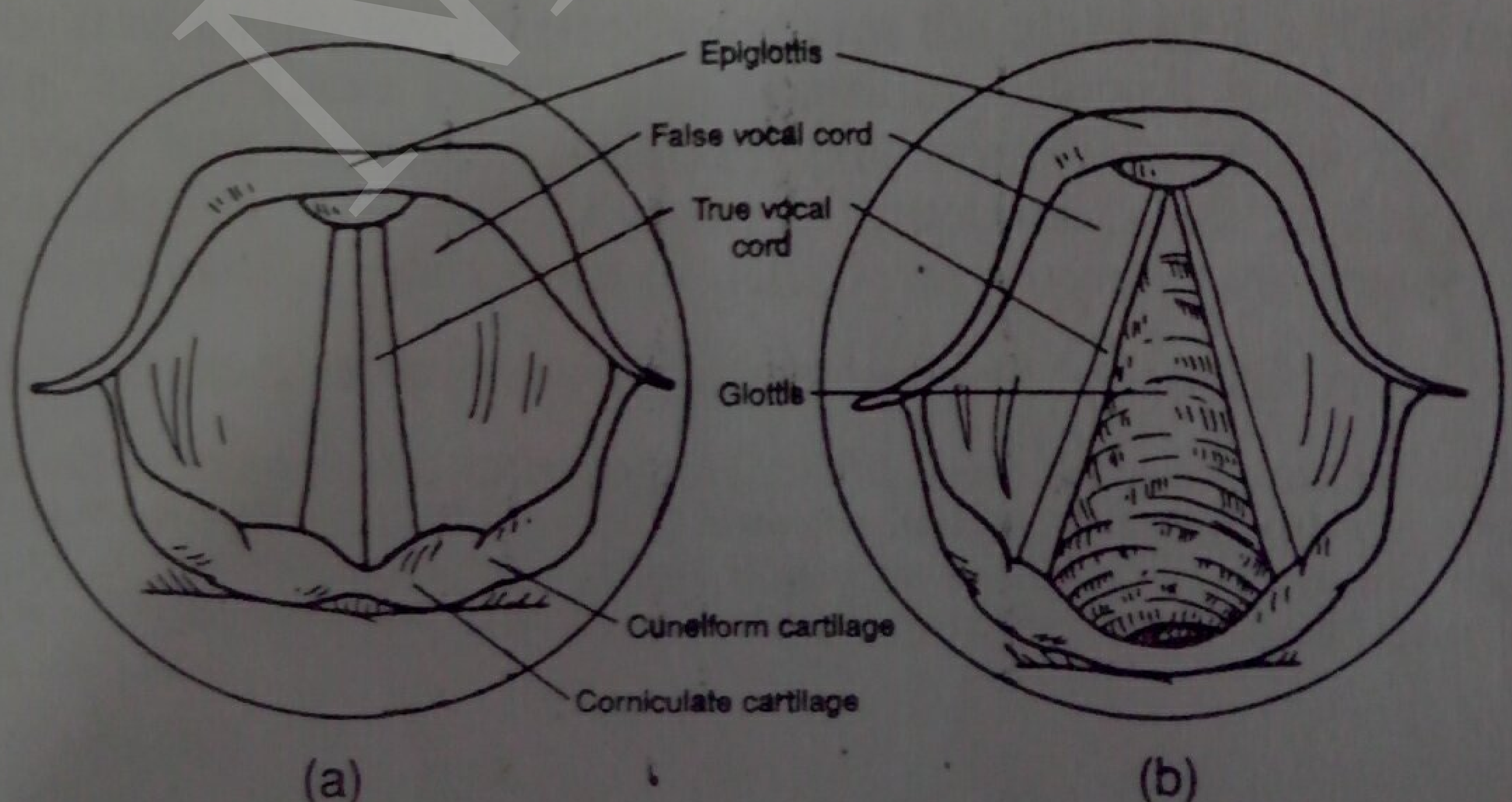

Figure 18.5 A superior view of (*a*) the opened and (*b*) the closed glottis.

18.10 Why not "Eve's apple"?

During puberty, the male sex hormone testosterone causes accelerated growth of the larynx, especially the thyroid cartilage. The larger larynx accounts for the deeper voice of males.

18.11 Explain the functional relationship between the glottis and epiglottis during swallowing.

During the final sequence of swallowing, the larynx is pulled superiorly, closing the glottis against the epiglottis. You can feel this movement by cupping your fingers lightly over the larynx and then swallowing.

With the glottis sealed, fluid or food enters the esophagus rather than the larynx and trachea. However, fluid or food may enter the glottis if it is not closed during swallowing as it should be. Fluid entering the trachea reflexively causes violent coughing in an attempt to force it out. Food entering the glottis may become lodged between the vocal cords. In this case, the *abdominal thrust* (Heimlich) *maneuver* can be used to prevent suffocation.

18.12 Explain how the laryngeal muscles aid in swallowing and in phonation (speech).

Extrinsic laryngeal muscles elevate the larynx during swallowing, closing the glottis over the epiglottis and opening the esophagus for food or fluid to enter. Contraction of the *intrinsic laryngeal muscles* changes the tension of the vocal cords. The greater the tension of the cords, the more rapid their vibration under the airstream and the higher the pitch of the sound (see problem 12.17). The greater the amplitude of vibration, the louder the sound. *Whispering* is phonation in which the vocal cords do not vibrate.

The muscles of the larynx are one of the few muscle groups to not completely relax during rapid-eye-movement (REM) sleep (thankfully, the diaphragm also maintains its function). The role of the laryngeal muscles is to keep the upper airway open during inspiration, a period in the respiratory cycle during which the negative intrathoracic pressure tends to pull the upper airway closed. In *sleep apnea*, the laryngeal muscles fail to maintain a patent airway, resulting in 30-second to 1-minute episodes of breathing cessation. Sleep apnea may be associated with snoring, daytime somnolence (due to lack of REM sleep at night), nighttime headaches (due to hypoxia), and lethargy. Pulmonary vascular hypertension due to hypoxia may ultimately lead to right ventricular heart failure and death. Obesity is one of the few recognized risk factors for sleep apnea.

Objective G To describe the *bronchial tree*.

The trachea divides inferiorly to form the **right** and **left primary bronchi** (fig. 18.6). These branch into **secondary** (*lobar*) **bronchi**, which in turn branch into numerous **tertiary** (*segmental*) **bronchi** that terminate in **bronchioles**. The entire system of branches is called the *bronchial tree*. Hyaline cartilaginous rings or partial rings support the trachea and the tree.

18.13 Describe three protective features of the trachea and bronchial tree.

The cartilaginous framework maintains patent (open) lumina. Mucus-secreting pseudostratified ciliated columnar epithelium (problem 18.6) lines the lumina, trapping airborne particles and moving this debris toward the pharynx, where it may be swallowed. Irritation to the epithelial lining of the trachea or bronchial tree elicits a violent coughing reflex that cleanses the respiratory tract.

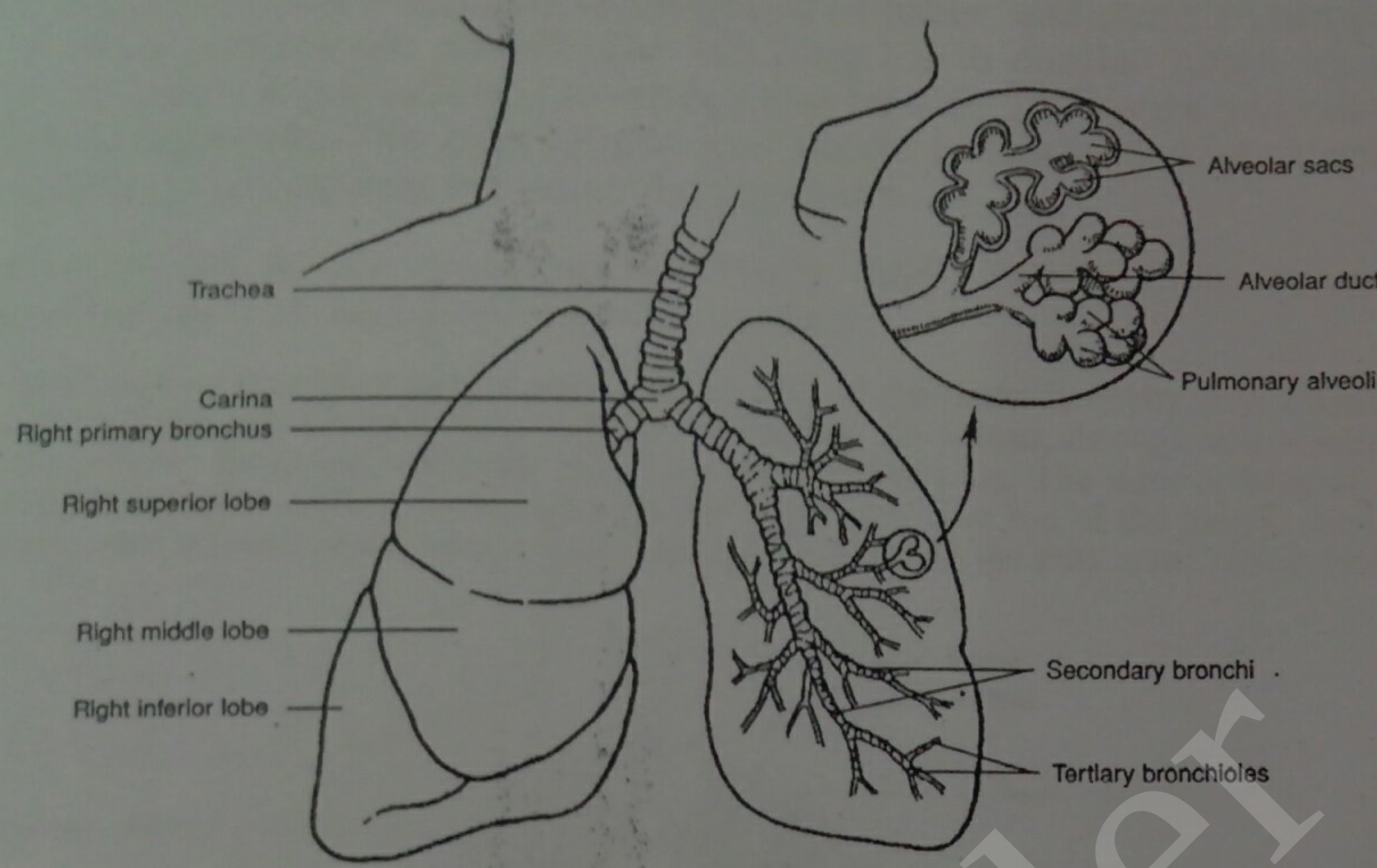

Figure 18.6 The trachea, lungs, and bronchial tree.

Objective H To describe the *respiratory division structures.*

Bronchioles end in **terminal bronchioles**, which branch into many **alveolar ducts** that lead directly into **alveolar sacs**, themselves clusters of many microscopic **pulmonary alveoli**. Alveolar ducts are lined with simple cuboidal epithelium, whereas pulmonary alveoli are lined with simple squamous epithelium. Gas exchange with the blood of the circulatory system occurs through the thin-walled, moistened pulmonary alveoli (see problem 18.2).

18.14 What are the functions of septal cells and alveolar macrophages?

Small **septal cells**, dispersed among the cells of the simple squamous epithelium lining a pulmonary alveolus, secrete a phospholipid *surfactant* that lowers the surface tension. Also found in the alveolar wall are phagocytic **alveolar macrophages** (*dust cells*) that remove dust particles or other debris from the pulmonary alveolus.

18.15 Diagram the process of external respiration (see problem 18.1) on the alveolar level.

See figure 18.7.

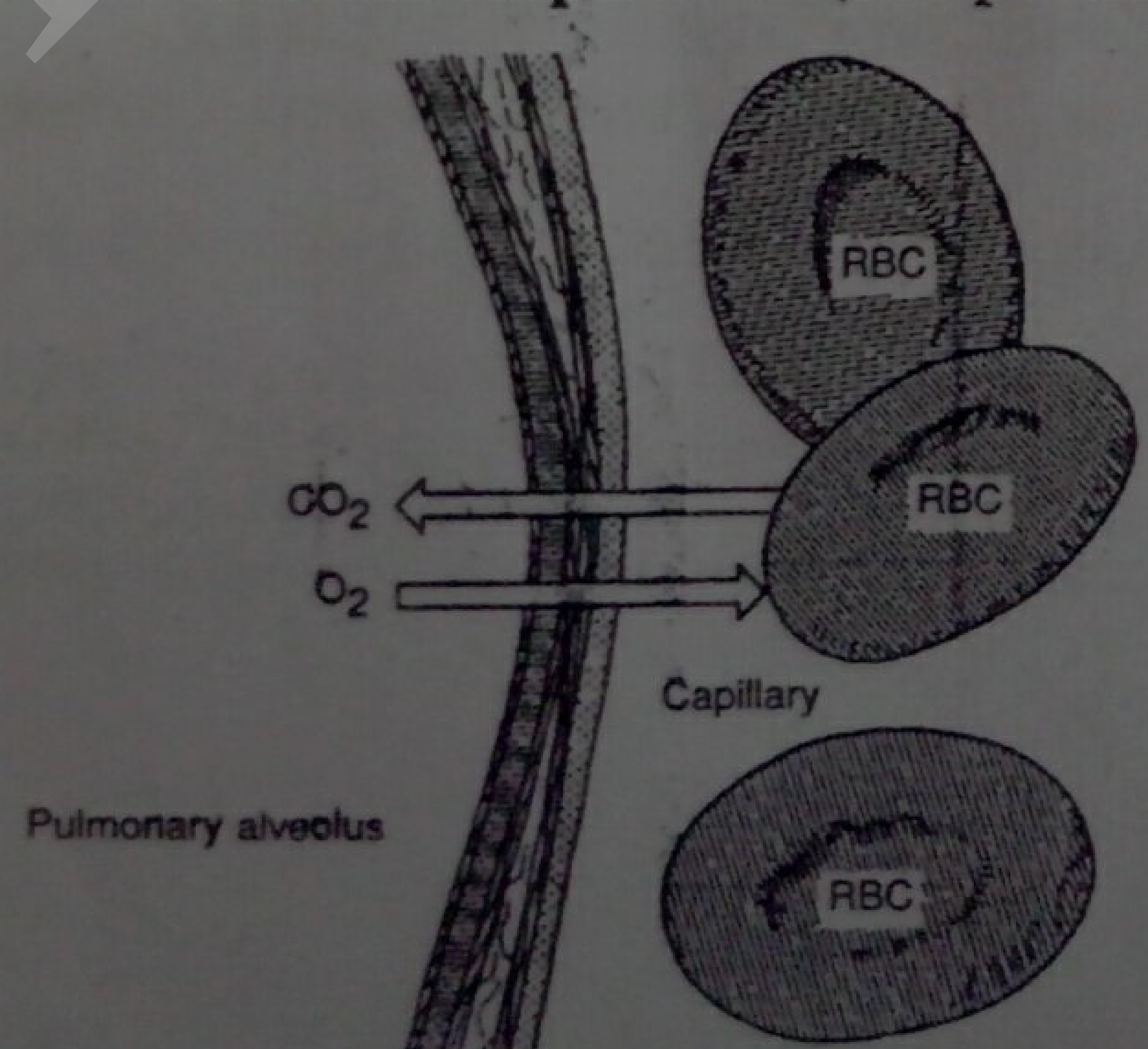

Figure 18.7 External respiration between a pulmonary alveolus and the blood within a capillary.

Objective I To describe the *lungs.*

The paired **lungs** are large, roughly cone-shaped organs contained within the thoracic cavity (fig. 18.8). They are separated from each other by the *mediastinum*. Each lung is composed of **lobes**, and these, in turn, of **lobules** that contain the alveoli. The left lung has a cardiac notch on its medial surface. It is subdivided into two lobes by a single **fissure** and contains eight **bronchial segments**. The right lung lacks a notch, is subdivided into three lobes by two fissures, and contains ten bronchial segments.

18.16 In reference to the lung, define the terms *apex, base, hilum, costal surface, mediastinal surface,* and *diaphragmatic surface.*

Each lung presents four borders that match the contour of the thoracic cavity. The **mediastinal surface** is slightly concave and has a vertical indentation, the **hilum**, through which pulmonary vessels, a primary bronchus, and branches of the vagus nerve pass. The inferior **base of the lung** has a **diaphragmatic surface** in contact with the diaphragm. The top of the lung is the **apex**, and the broad, rounded surface in contact with membranes covering the ribs is the **costal surface**.

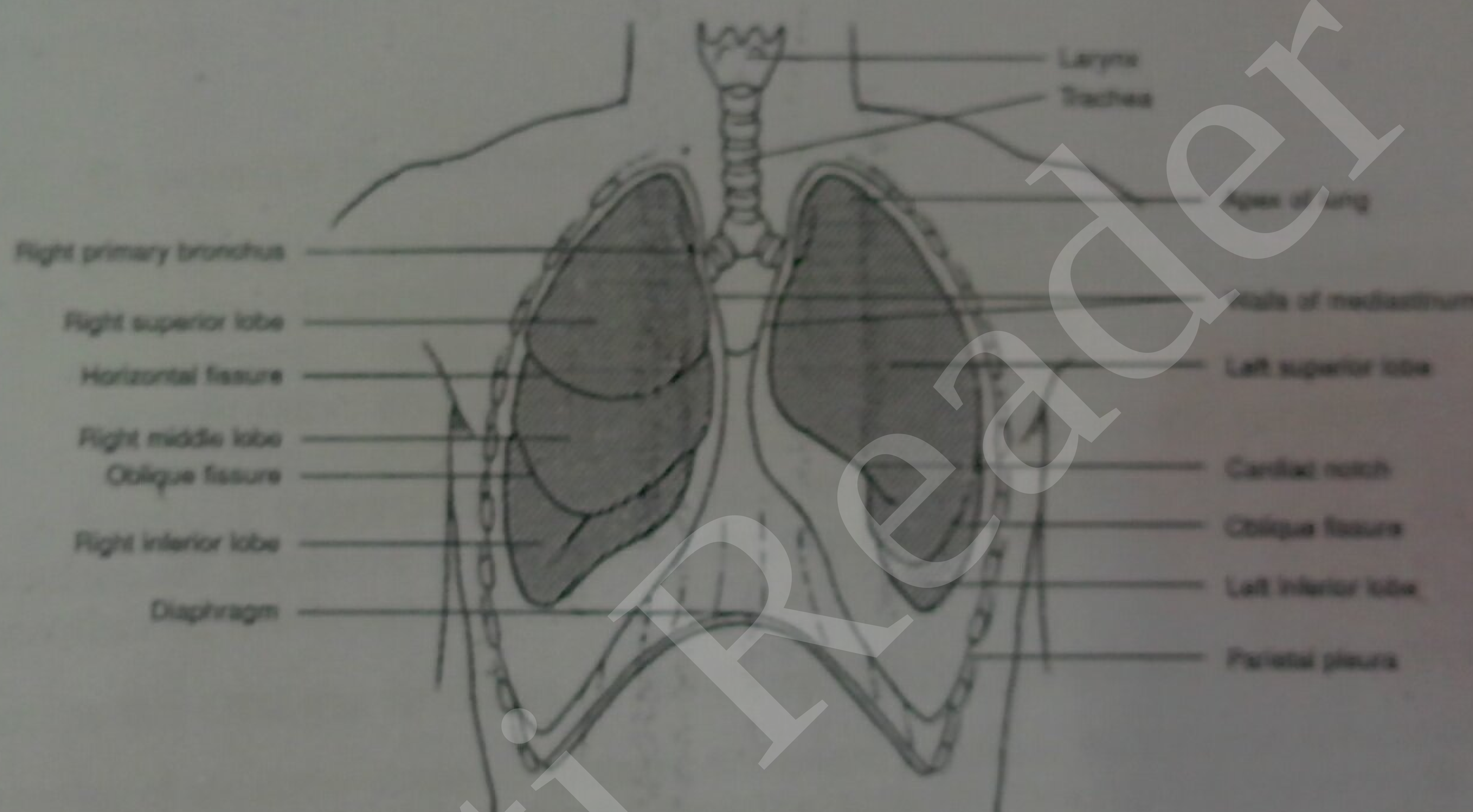

Figure 18.8 The lungs within the thoracic cavity.

Objective J To describe the *pleurae* and to explain their respiratory significance.

Pleurae are two-layer serous membranes associated with the lungs. They are composed of simple squamous epithelium and fibrous connective tissue. The inner layer, or **visceral pleura**, is attached to the surface of the lungs; the outer layer, or **parietal pleura** (fig. 18.8), lines the thoracic cavity. Pleurae serve to lubricate the lungs, and they assist in creating respiratory pressure. (For an important nonrespiratory function, see problem 1.22.)

18.17 How do the pleurae perform their respiratory functions?

Between the visceral and parietal pleurae of each lung is a damp **pleural cavity**. This moist environment serves to lubricate the lungs in their constant motion. Air pressure in each pleural cavity (the *intrathoracic pressure)* is slightly below atmospheric pressure (–2.5 mmHg, approximately) in the resting lungs, and becomes even lower during inspiration, causing air to inflate the lungs.

Pleurisy, or inflammation of the pleurae, may be secondary to some other respiratory disease or due to an autoimmune reaction associated with viral infections or autoimmune diseases. Chest pain is felt most keenly when breathing deeply or lying down. Anti-inflammatories, such as aspirin, ibuprofen, and corticosteroids, are used in treating pleurisy.

The *pleural cavity* is a potential space only. Under normal conditions the visceral and parietal pleurae are pressed tightly against one another due to the relative negative pressure in the space. This negative pressure is critical for the thoracic cavity to "pull out" on the lungs causing them to inflate. Air in the pleural space (from a hole in the chest wall or a hole in the visceral pleura) disturbs this vital homeostasis so that the lung collapses despite active expansion of the chest wall. This condition is called *pneumothorax*.

Objective K To examine the *mechanics of breathing*.

Inspiration (see problem 18.4) occurs when contraction of the respiratory muscles (diaphragm, internal intercostals; see table 8.4) causes an increase in thoracic volume, with expansion of the lungs and a decrease in intrathoracic and *intrapulmonic* (alveolar) pressures. Air enters the lungs when intrapulmonic pressure falls below atmospheric pressure (760 mmHg at sea level). **Expiration** follows passively as thoracic volume decreases and intrapulmonic pressure rises above atmospheric, with recoil of the rib cage and contraction of the lungs.

18.18 Describe the changes in shape of the thorax during inspiration and expiration.

Contraction of the dome-shaped diaphragm downward increases the thoracic vertical dimension. A simultaneous contraction of the external intercostal muscles (see fig. 8.4) increases the side-to-side and front-to-back dimensions. During deep inspiration or forced breathing, the scalenes and sternocleidomastoid muscles (see fig. 8.3), as well as the pectoralis minor muscles (see table 8.8), become involved. During forced expiration, the internal intercostal muscles are contracted, depressing the rib cage. Contracting the abdominal muscles (see table 8.6) also forces air from the lungs by elevating the diaphragm.

Objective L To identify the various *respiratory air volumes*.

The *total lung capacity* may be expressed as the sum of four volumes (fig. 18.9). These are the **tidal volume**, the volume of air moved into and out of the lungs during normal breathing; **inspiratory reserve**, the maximum volume beyond the tidal volume that can be inspired in one deep breath; **expiratory reserve**, the maximum volume beyond the tidal volume that can be forcefully exhaled following a normal expiration; and **residual volume**, the air that remains in the lungs following a forceful expiration. Respiratory air volumes are measured with the *spirometer*.

18.19 Account for the variability of respiratory air volumes.

Clinically speaking, it is important to know the amount of air that is breathed in at a given time and to be aware of difficulty in breathing. The amount of air exchanged during pulmonary ventilation varies from person to person according to age, sex, activity, and general health.

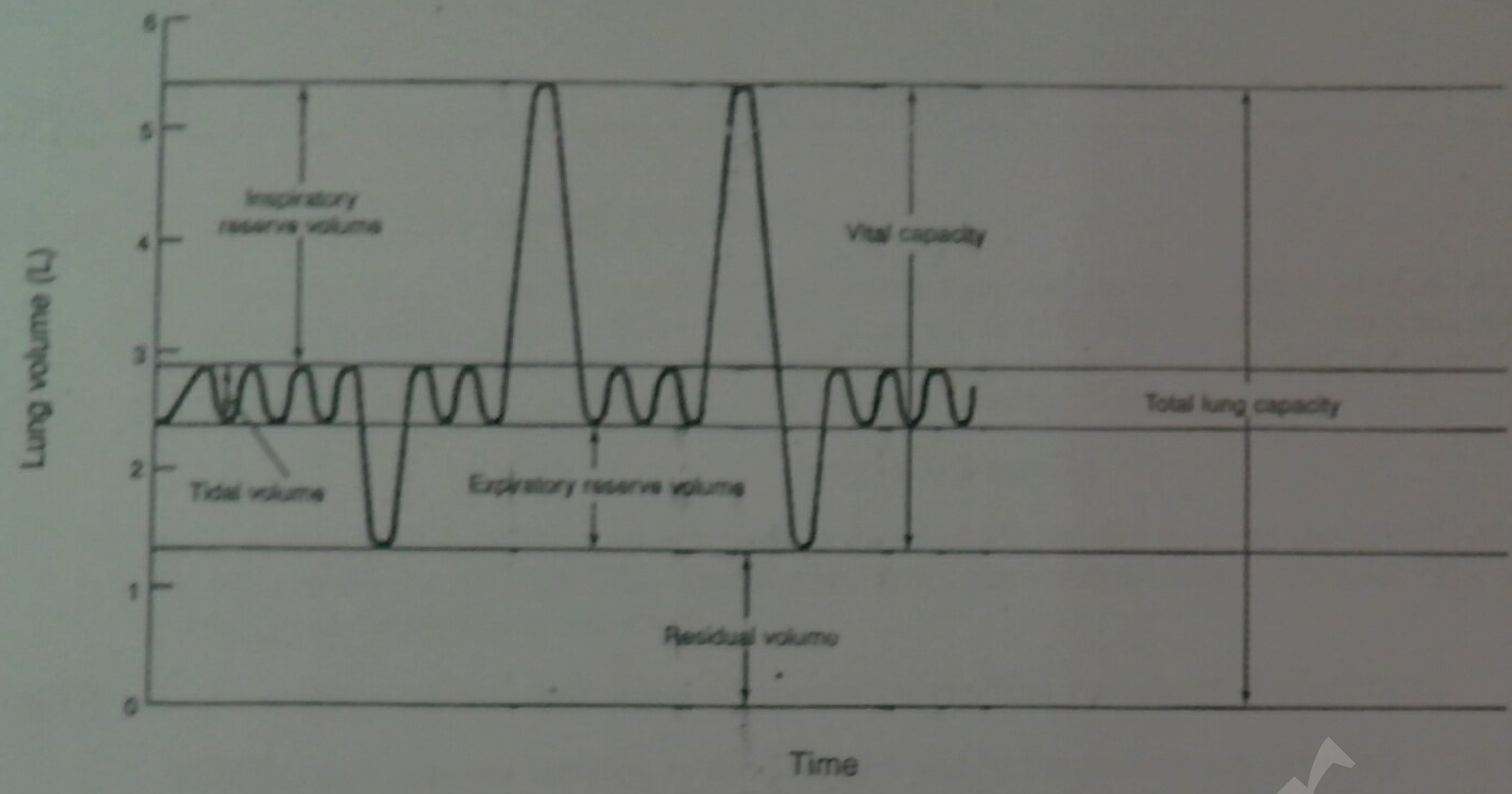

Figure 18.9 Respiratory air volumes.

18.20 Calculate the minute respiratory volume of an individual who has a tidal volume of 500 ml and a respiratory rate of 12 breaths per minute.

Minute respiratory volume is the volume of air moved in normal ventilation in one minute. Therefore,

$$\text{Minute respiratory volume} = (\text{tidal volume}) \times (\text{respiratory rate})$$
$$= (0.500 \text{ L}) \times (12 \text{ min}^{-1}) = 6 \text{ L/min}$$

The preceding is a typical example.

18.21 Define *alveolar ventilation*.

Alveolar ventilation is the volume of air exchanged in 1 minute in the pulmonary alveoli (for transport to the cells). Thus,

$$\text{Alveolar ventilation} = [(\text{tidal volume}) - (\text{dead space})] \times (\text{respiratory rate})$$

Dead space is defined as the volume of air between the mouth/nose and the pulmonary alveoli, or that space that is not involved in gas exchange. This is typically 150 ml in an adult.

Objective M To describe the transport of gases between the lungs and the cells.

Of the oxygen transported in the blood, only a small amount is dissolved in the blood plasma. Up to 99% is carried on hemoglobin molecules in the erythrocytes (see problem 14.9). Carbon dioxide carried in the blood is mostly converted to bicarbonate ions in the erythrocytes and released into the blood plasma; unconverted carbon dioxide is also carried dissolved in the blood plasma and on hemoglobin molecules and certain plasma proteins.

18.22 Use an equation to define the oxygenation of hemoglobin.

Hemoglobin is converted from bluish-red *deoxyhemoglobin* (Hb) to scarlet *oxyhemoglobin* (HbO_2) according to the reaction

$$Hb + O_2 \longleftrightarrow HbO_2$$

18.23 What is meant by partial pressure?

In a mixture of gases, each component gas exerts a *partial pressure* that is proportional to its concentration in the mixture. For example, since air is 21% O_2, this gas is responsible for 21% of the atmospheric pressure. Since 21% of 760 mmHg is equal to 160 mmHg, the partial pressure of O_2, symbolized by P_{O_2}, in atmospheric air is 160 mmHg. Similarly,

$$P_{CO_2} = 0.3 \text{ mmHg}$$

The partial pressures of oxygen and carbon dioxide are not the same in the alveoli as they are in the atmosphere due to the high CO_2 contribution from the venous blood. Alveolar P_{O_2} is 101 mmHg and P_{CO_2} is 40 mmHg at sea level.

18.24 Explain respiratory diffusion in terms of partial pressure differences.

The difference between the P_{O_2} in the alveolus and in the pulmonary capillary ($P_{O_2} = 40$) is about 60 mmHg and therefore favors diffusion of oxygen from the alveolus into the blood. A similar calculation of the difference between the P_{CO_2} in the pulmonary capillary ($P_{CO_2} = 45$) and in the alveolus demonstrates a gradient of 5 mmHg, favoring diffusion of carbon dioxide from the blood to the alveolar air.

18.25 What factors precipitate release of O_2 from hemoglobin to body tissues?

1. A decreased concentration of O_2 in the blood plasma
2. A decreased blood pH (i.e., an increased H^+ concentration)
3. An increased body temperature

Objective N To describe the role of the respiratory system in the *acid-base balance* of the body.

survey

The presence of the enzyme **carbonic anhydrase** in the erythrocytes causes about 67% of the CO_2 in blood to combine quickly with water to form carbonic acid, most of which dissociates into bicarbonate and hydrogen ions:

$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow HCO_3^- + H^+$$

18.26 Define *alkali reserve* and *chloride shift.*

Bicarbonate ions (HCO_3^-), which make up a large part of the blood buffer system, constitute the alkali reserve. As these ions leave erythrocytes, they cause an excess of negative charge, which is relieved by the diffusion of chloride ions (Cl^-) from the blood into the cells. This movement of chloride ions is termed the **chloride shift**.

18.27 Define *respiratory acidosis* and *respiratory alkalosis.*

Respiratory acidosis, or a process that drives blood pH below 7.35, occurs when CO_2 is not eliminated from the body at a normal rate, thus increasing vascular P_{CO_2}. Lung disease or decreased mental status resulting in hypoventilation may cause respiratory acidosis. **Respiratory alkalosis**, a process that drives blood pH above 7.45, occurs when CO_2 is eliminated too rapidly, thus decreasing vascular P_{CO_2}. Either hyperventilation or the action of certain drugs (such as excessive aspirin) on the respiratory control center of the brain may produce respiratory alkalosis. The effects of hyperventilation are rapidly reversed when the person breathes into a paper bag, inhaling expired air and so causing the vascular P_{CO_2} to rise.

Objective O To describe *neural* and *chemical regulation of respiration.*

The locations of the respiratory centers in the CNS are shown in fig. 18.10 (see also fig. 10.7). The rhythmicity area of the medulla oblongata is actually composed of separate **expiratory** and **inspiratory centers**. The medulla oblongata also contains chemoreceptors concerned with respiration (fig. 18.10), as do the **carotid bodies** in the neck and **aortic bodies** in the thorax (fig. 18.11).

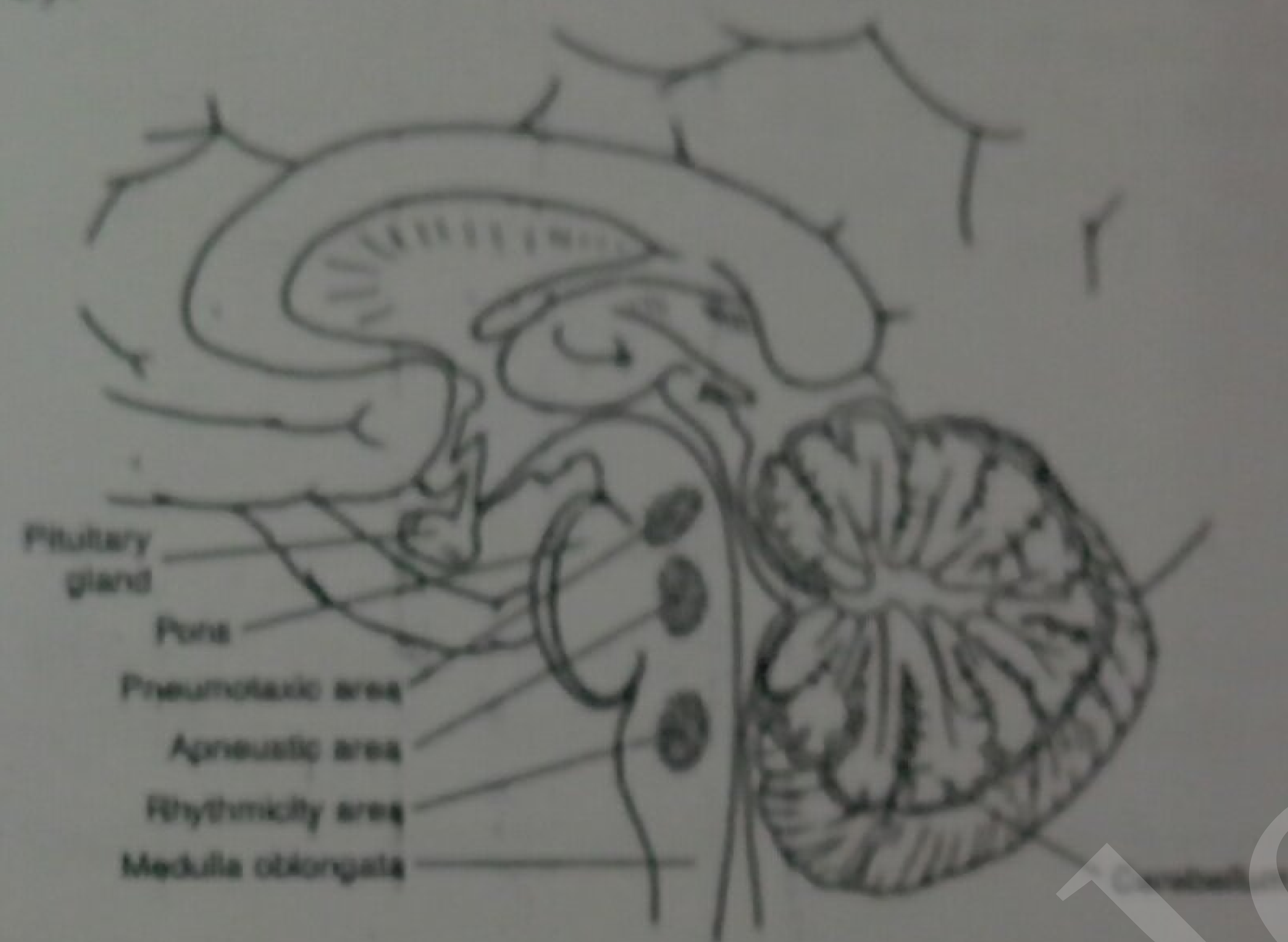

Figure 18.10 Respiratory control centers.

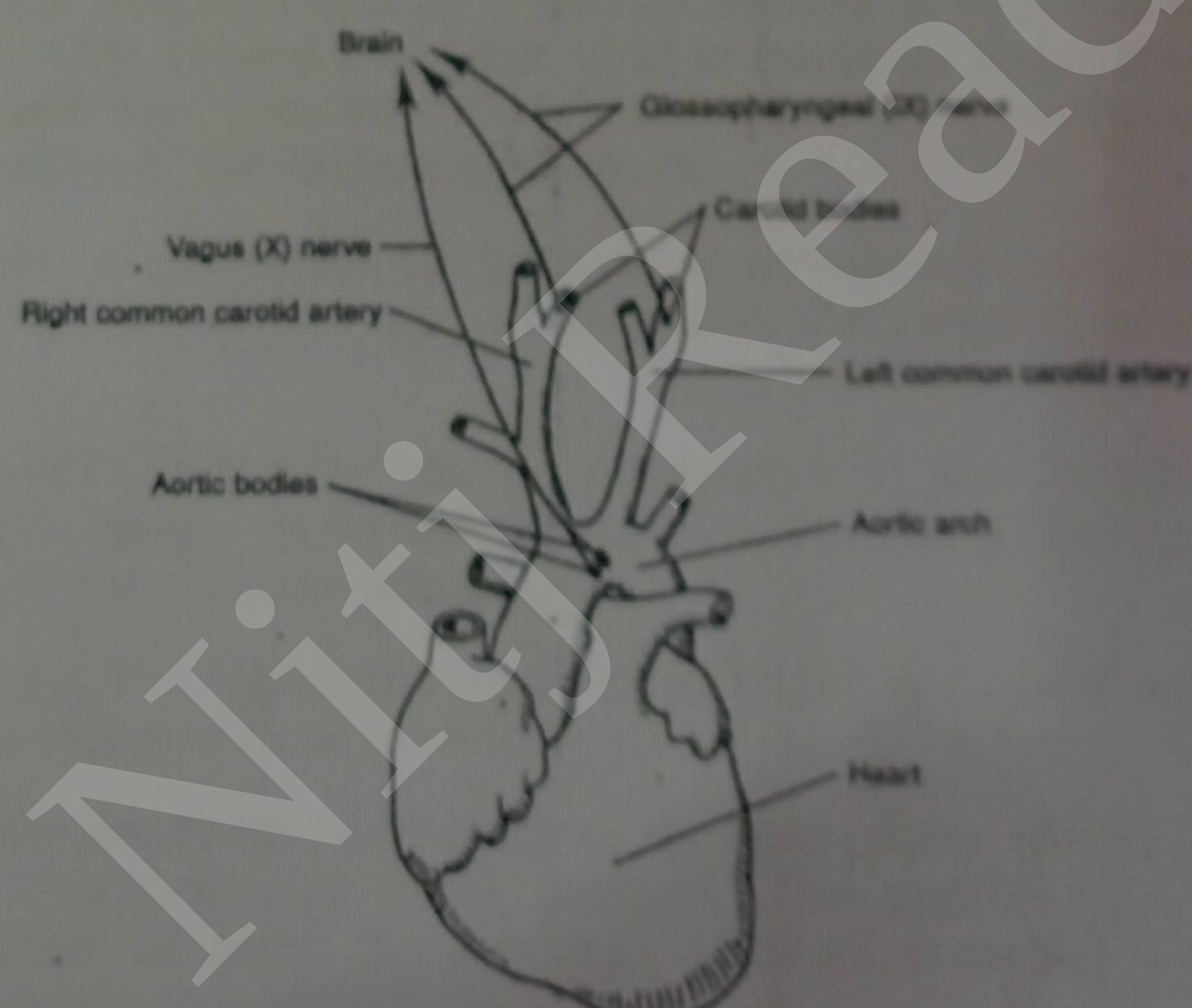

Figure 18.11 The carotid and aortic bodies.

18.28 How do the neural respiratory centers operate?

The rhythmicity area of the medulla oblongata consists of two intermingled groups of neurons. When the *inspiratory group* is excited (via the apneustic center), the respiratory muscles are signaled to accomplish inbreathing; at the same time, the *expiratory group* is inhibited. After about 2 seconds, the reciprocal process occurs; the pneumotaxic center stimulates the expiratory group to signal for exhaling, with simultaneous inhibition of the inspiratory group.

18.29 How do the respiratory chemoreceptors operate?

Central chemoreceptors, on the surface of the medulla oblongata, respond to increased P_{CO_2} or decreased pH of cerebrospinal fluid by initiating increased inspiration. Peripheral chemoreceptors, in the carotid and aortic bodies, respond to decreased P_{CO_2} by initiating increased inspiration.

The ability of the body to regulate acid/base status is one of the most elegant homeostatic mechanisms known. Almost immediately, an increase in pH caused by a loss of acid (through vomiting stomach secretions, for example) will result in a slowing of breathing, while a drop in pH (possibly due to diabetic ketoacidosis) will promote hyperventilation. Through this mechanism, the body is able to quickly reestablish normal pH.

Key Clinical Terms

Anoxia A severe shortage of oxygen in tissues and organs. Anoxia of the brain results in cell destruction within 30 seconds and in death generally within 5 to 10 minutes.

Apnea A temporary cessation of breathing that may follow hyperventilation.

Asphyxia Suffocation.

Asthma A disease characterized by recurrent attacks of dyspnea and wheezing. It may be aggravated by inhaled allergens, viral or bacterial upper respiratory infections, cold air, or exercise. The attacks are provoked by constriction of the airways and inflammation of the bronchial mucosa.

Bronchitis, acute Inflammation of the mucous membrane lining the bronchial tubes. Viral and bacterial infections, air pollution, and allergies may be causative or contributing factors.

Bronchitis, chronic Excessive mucus production in the bronchial tubes that leads to productive cough, shortness of breath, and lung damage. It is caused almost exclusively by cigarette smoking.

Cleft lip A genetic developmental disorder in which the two sides of the upper lip fail to fuse; also referred to as *harelip*.

Cleft palate A developmental deformity of the hard palate, resulting in a persistent opening between the oral and nasal cavities. The condition may be hereditary or a complication of some disease (e.g., German measles) contracted by the mother during pregnancy.

Dyspnea Difficult breathing.

Emphysema A breakdown of the alveolar walls that decreases the alveolar surface area and increases the size of air spaces distal to the terminal bronchioles. It is a frequent cause of death among heavy cigarette smokers and may also result from severe air pollution.

Epistaxis Nosebleed.

Hiccup A spasmodic contraction of the diaphragm causing a rapid, involuntary inhalation that is stopped by the sudden closure of the glottis and accompanied by a distinctive sound; also spelled *hiccough*.

Hyperventilation Excessive inhalation and exhalation.

Laryngitis Inflammation of the larynx.

Pleurisy Inflammation of the pleurae.

Pneumonia Acute infection and inflammation of the lungs, with exudation of fluids into, and consolidation (collapse) of, lung tissue.

Rhinitis Inflammation of the nasal mucosa.

Sinusitis Inflammation of the mucous membrane of one or another of the paranasal sinuses—usually secondary to a nasal infection.

Tuberculosis An inflammatory disease of the lungs, caused by the tubercle bacillus, in which the tissue caseates (becomes cheesy) and ulcerates. The disease is usually contracted by inhaling air sneezed or coughed by someone with an active case.

Review Exercises

Multiple Choice

1. Which is *not* a structure of the respiratory system? (*a*) the pharynx, (*b*) the bronchus, (*c*) the larynx, (*d*) the hyoid (*e*) the trachea
2. The roof of the nasal cavity is formed primarily by (*a*) the hard palate, (*b*) the cribriform plate of the ethmoid bone, (*c*) the superior concha, (*d*) the vomer, (*e*) the sphenoid bone.
3. The cartilages upon which the vocal cords are attached are (*a*) the thyroid and arytenoid cartilages, (*b*) the thyroid and cricoid cartilages, (*c*) the cuneiform and cricoid cartilages, (*d*) the thyroid and corniculate cartilages.
4. Pulmonary vessels, nerves, and a bronchus enter or leave the lung at (*a*) the cardiac notch, (*b*) the apex, (*c*) the capsule, (*d*) the hilum, (*e*) the base.
5. Neither the trachea nor the bronchi contain (*a*) hyaline cartilage, (*b*) ciliated columnar epithelium, (*c*) goblet cells, (*d*) simple squamous epithelium.
6. Pharyngeal tonsils are located in (*a*) the nasopharynx, (*b*) the oral cavity, (*c*) the nasal cavity, (*d*) the oropharynx, (*e*) the lingualopharynx.
7. Which of the following is a *false* statement?
   (*a*) Slacker vocal cords produce higher sounds.
   (*b*) During swallowing, the epiglottis is depressed to cover the glottis.
   (*c*) In whispering, the vocal cords do not vibrate.
   (*d*) Testosterone secretion influences laryngeal development during puberty.
8. The serous membrane in contact with the lung is (*a*) the parietal pleura, (*b*) the pulmonary mesentery, (*c*) the pulmonary peritoneum, (*d*) the visceral pleura.
9. Most of the CO_2 is transported in the blood as (*a*) carboxyhemoglobin, (*b*) HCO_3^-, (*c*) carbaminohemoglobin, (*d*) dissolved CO_2.
10. Peripheral chemoreceptors are located in (*a*) lung tissue, (*b*) the pons and medulla oblongata, (*c*) aortic and carotid bodies, (*d*) the myocardium.
11. As CO_2 produced in the tissues combines with H_2O in the blood, (*a*) carbonic acid is formed, (*b*) Cl^- enters the blood, (*c*) most of the HCO_3^- from the carbonic acid leaves the RBCs for the blood plasma, (*d*) all of the preceding occur.