# THE RESPIRATORY SYSTEM I

## Organs and Structures of the Respiratory System

**Figure 22.1 Mountain Climbers** The thin air at high elevations can strain the human respiratory system. (credit:“bortescristian”/flickr.com)

This module is based on an edited version of the OpenStax book which is available for free at http://cnx.org/content/col11496/1.8

The major organs of the respiratory system function primarily to provide oxygen to body tissues for cellular respiration, remove the waste product carbon dioxide, and help to maintain acid-base balance. Portions of the respiratory system are also used for non-vital functions, such as sensing odours, speech production, and for straining, such as during childbirth or coughing (**Figure 22.2**).

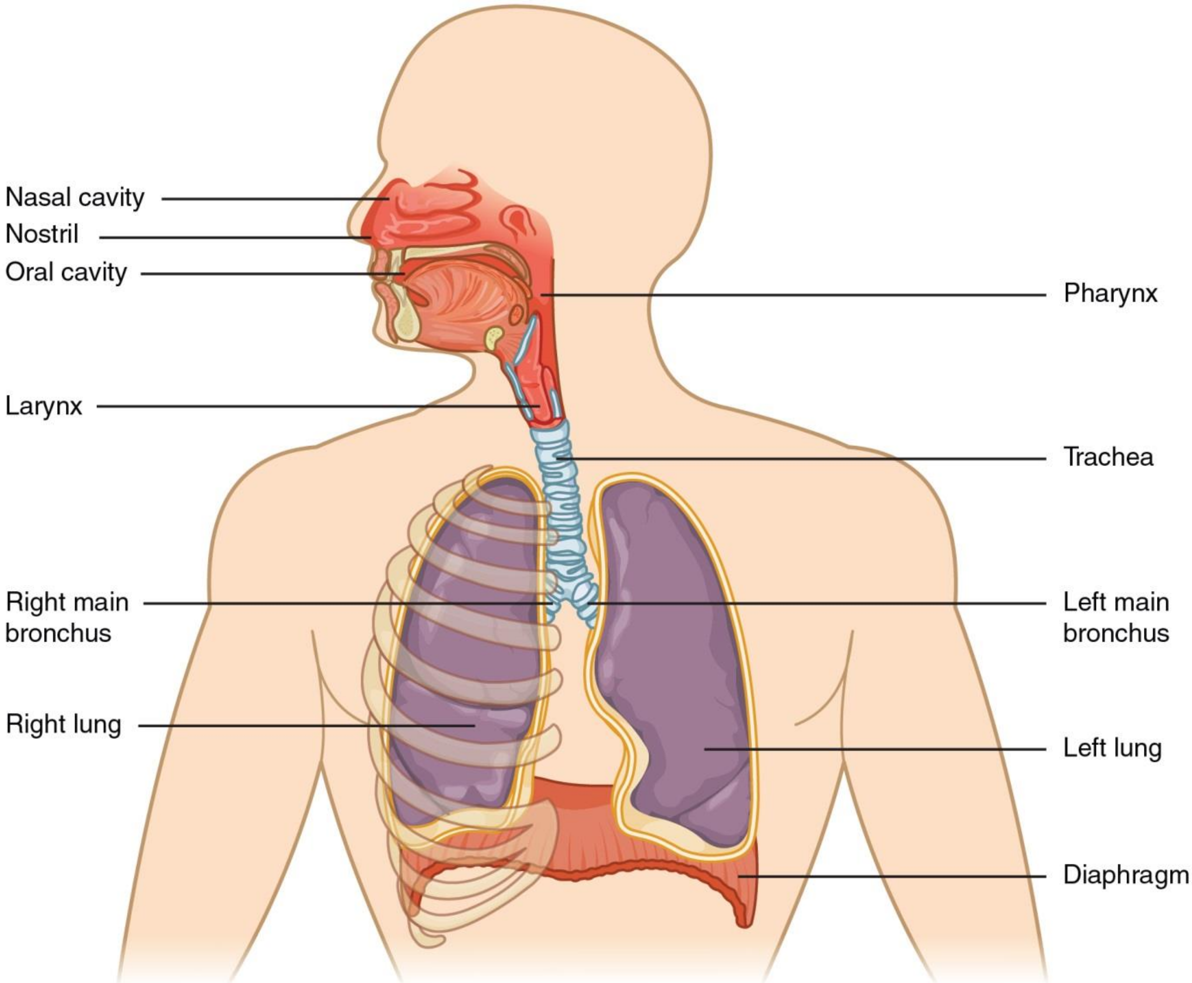


**Figure 22.2 Major Respiratory Structures** The major respiratory structures span the nasal cavity to the diaphragm.

Functionally, the respiratory system can be divided into a conducting zone and a respiratory zone. The **conducting zone** of the respiratory system includes the organs and structures not directly involved in gas exchange. The gas exchange occurs in the **respiratory zone**.

## Conducting Zone

The major functions of the conducting zone are to provide a route for incoming and outgoing air, remove debris and pathogens from the incoming air, and warm and humidify the incoming air. Several structures within the conducting zone perform other functions as well.  The epithelium (surface cells) of the nasal passages, for example, is essential to sensing odours, and the bronchial epithelium that lines the lungs can metabolise some airborne carcinogens. Note that the total volume of the conducting portion is approximately 0.15 litres, whilst that of the respiratory portion is 5 – 6 litres.

### The Nose and its Adjacent Structures

The major entrance and exit for the respiratory system is through the nose. When discussing the nose, it is helpful to divide it into two major sections: the external nose, and the nasal cavity or internal nose.
The external nose consists of the surface and skeletal structures that result in the outward appearance of the nose and contribute to its numerous functions (Figure 22.3).

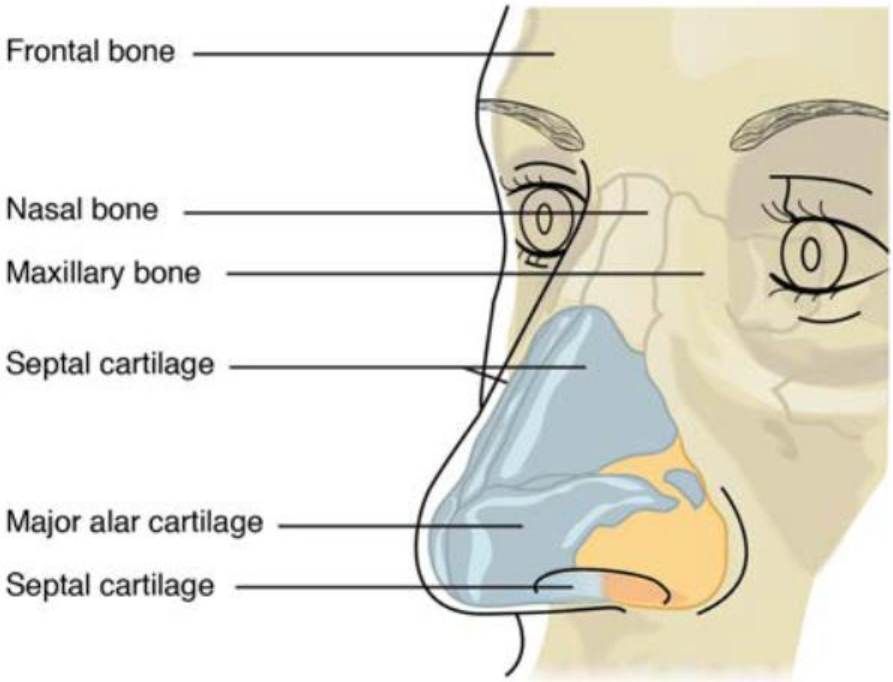


**Figure 22.3 Nose** This illustration shows features of the external nose (top) and skeletal features of the nose.

Underneath the thin skin of the nose are its skeletal features (see Figure 22.3). While the root and bridge of the nose consist of bone, the protruding portion of the nose is composed of cartilage. As a result, when looking at a skull, the nose is missing.

The nares (nostrils) open into the nasal cavity, which is separated into left and right sections by the nasal septum (Figure 22.4). Each side wall of the nasal cavity has three bony projections, called the superior, middle, and inferior nasal conchae. Conchae serve to increase the surface area of the nasal cavity and to disrupt the flow of air as it enters the nose, causing air to bounce along the surface, where it is cleaned and warmed. The conchae and **meatuses** (spaces between the conchae) also conserve water and prevent dehydration of the nasal surfaces by trapping water during exhalation.

The floor of the nasal cavity is composed of the palate. The hard palate at the front of the nasal cavity is composed of bone. The soft palate at the rear of the nasal cavity consists of muscle tissue. Air exits the nasal cavities via the internal nares and moves into the pharynx.

Several bones that help form the walls of the nasal cavity have air-containing spaces called the paranasal sinuses, which serve to warm and humidify incoming air. Sinuses are lined with a mucosa. Each paranasal sinus is named for its associated bone: frontal sinus, maxillary sinus, sphenoidal sinus, and ethmoidal sinus. The sinuses produce mucus and lighten the weight of the skull.

The nares and front portion of the nasal cavities are lined with mucous membranes, containing sebaceous glands (oil producing glands) and hair follicles that serve to prevent the passage of large debris, such as dirt, through the nasal cavity. An olfactory epithelium used to detect odours is found deeper in the nasal cavity.

The conchae, meatuses, and paranasal sinuses are lined by respiratory epithelial (surface) cells. The specialised goblet cells produce mucus to trap debris. The cilia of the respiratory epithelium help remove the mucus and debris from the nasal cavity with a constant beating motion, sweeping materials towards the throat to be swallowed. Interestingly, cold air slows the movement of the cilia, resulting in accumulation of mucus that may in turn lead to a runny nose during cold weather.

Serous and mucus-producing cells also secrete enzyme and proteins which have antibacterial properties. Immune cells that patrol the connective tissue deep to the respiratory epithelium provide additional protection.

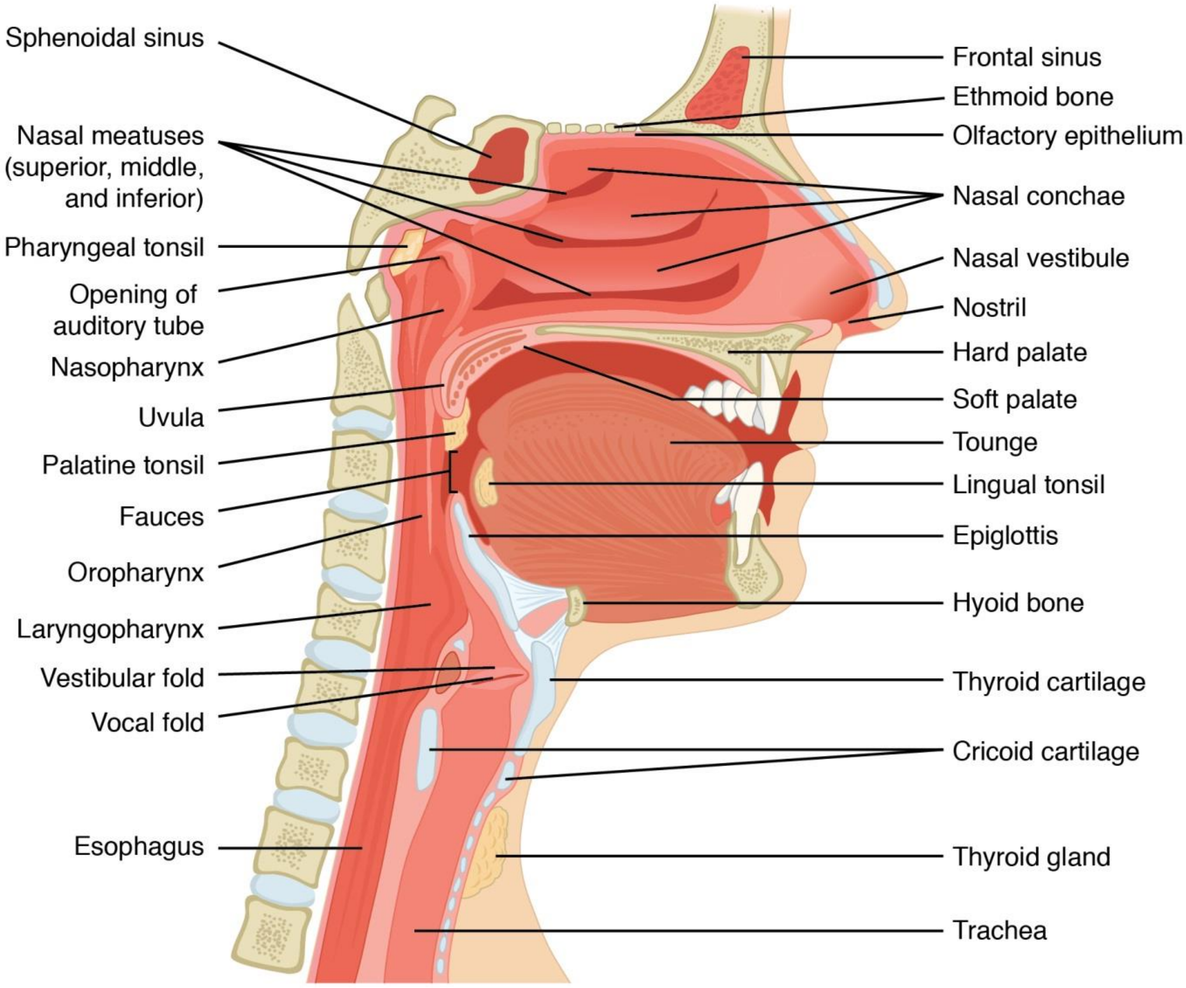


**Figure 22.4 Upper Airway**

The **nasopharynx** serves only as an airway. At the top of the nasopharynx are the pharyngeal tonsils. A **pharyngeal tonsil**, also called an adenoid, is a collection of lymphoid tissue similar to a lymph node that lies at the top of the nasopharynx. The function of the pharyngeal tonsil is not well understood, but it contains a rich supply of lymphocytes and is covered with ciliated epithelium that traps and destroys invading pathogens that enter during inhalation. The pharyngeal tonsils are large in children, but interestingly, tend to regress with age and may even disappear.

The uvula is a small bulbous, teardrop-shaped structure located at the tip of the soft palate. Both the uvula and soft palate move like a pendulum during swallowing, swinging upward to close off the nasopharynx to prevent ingested materials from entering the nasal cavity.

In addition, auditory (Eustachian) tubes that connect to each middle ear cavity open into the nasopharynx. This connection is why colds often lead to ear infections.

The oropharynx is a passageway for both air and food. The oropharynx is bordered above by the nasopharynx and at the front by the oral cavity. The oropharynx contains two distinct sets of tonsils, the palatine and lingual tonsils. A palatine tonsil is one of a pair of structures located in the area between the oral cavity and the oropharynx. These are the tonsils removed in a tonsillectomy.

The **lingual tonsil** is located at the base of the tongue. Similar to the pharyngeal tonsils, both the palatine and lingual tonsils are composed of lymphoid tissue, and trap and destroy pathogens entering the body through the oral or nasal cavities.

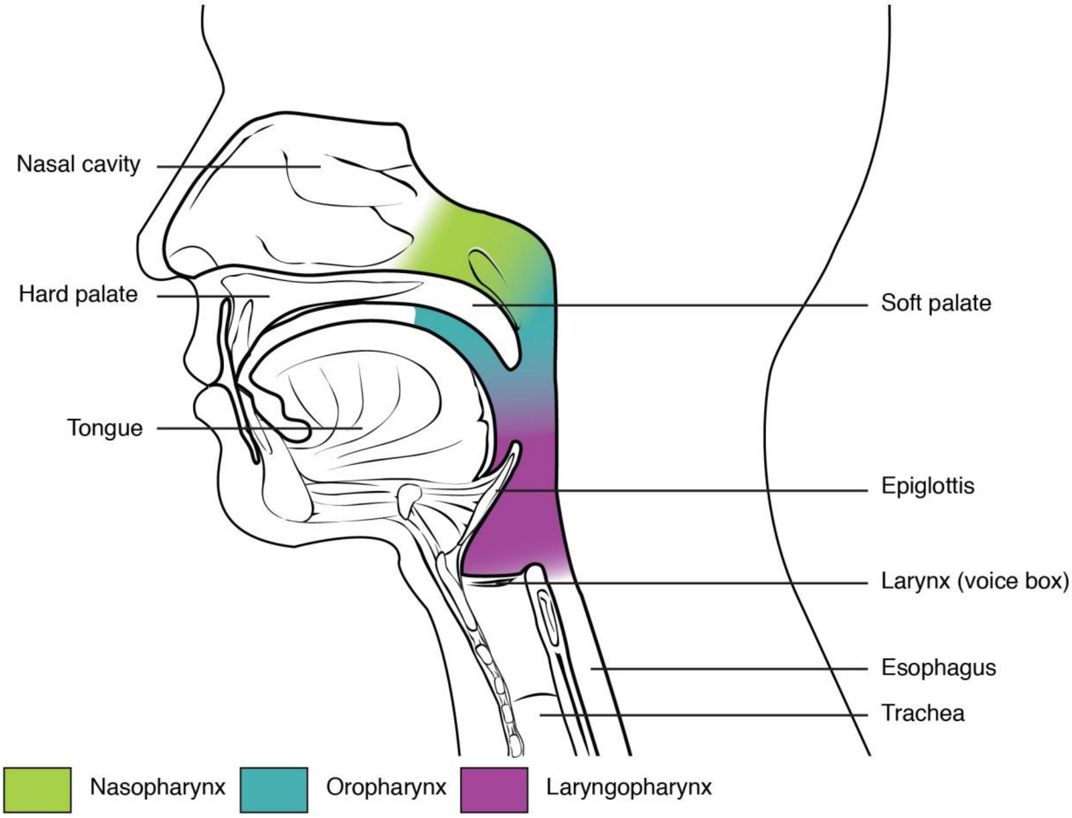


**Figure 22.6 Divisions of the Pharynx** The pharynx is divided into three regions: the nasopharynx, the oropharynx, and the laryngopharynx.

The **laryngopharynx** is below the oropharynx. It continues the route for ingested material and air until the digestive and respiratory systems diverge. At the front, the laryngopharynx opens into the larynx, whereas the rear it enters the oesophagus.

## Larynx

The **larynx** is a cartilaginous structure below the laryngopharynx that connects the pharynx to the trachea and helps regulate the volume of air that enters and leaves the lungs (Figure 22.7). The structure of the larynx is formed by several pieces of cartilage. Three large cartilage pieces—the thyroid cartilage, epiglottis, and cricoid cartilage —form the major structure of the larynx.

The **thyroid cartilage** is the largest piece of cartilage that makes up the larynx. The thyroid cartilage consists of the **laryngeal prominence**, or "Adam's apple," which tends to be more prominent in males.
The thick **cricoid cartilage** forms a complete ring, with a wide rear region and a thinner front. Is the only complete ring of cartilage around the trachea.
Three smaller, paired cartilages—the arytenoids, corniculates, and cuneiforms—attach to the epiglottis and the vocal cords and muscle that help move the vocal cords to produce speech.

The **epiglottis**, attached to the thyroid cartilage, is a very flexible piece of elastic cartilage that covers the opening of the trachea (see Figure 22.4). When in the "closed" position, the unattached end of the epiglottis rests on the glottis therefore preventing food passing into the trachea.

The **glottis** is composed of the vestibular folds, the true vocal cords, and the space between these folds (Figure 22.8). A **vestibular fold**, or false vocal cord, is one of a pair of folded sections of mucous membrane.

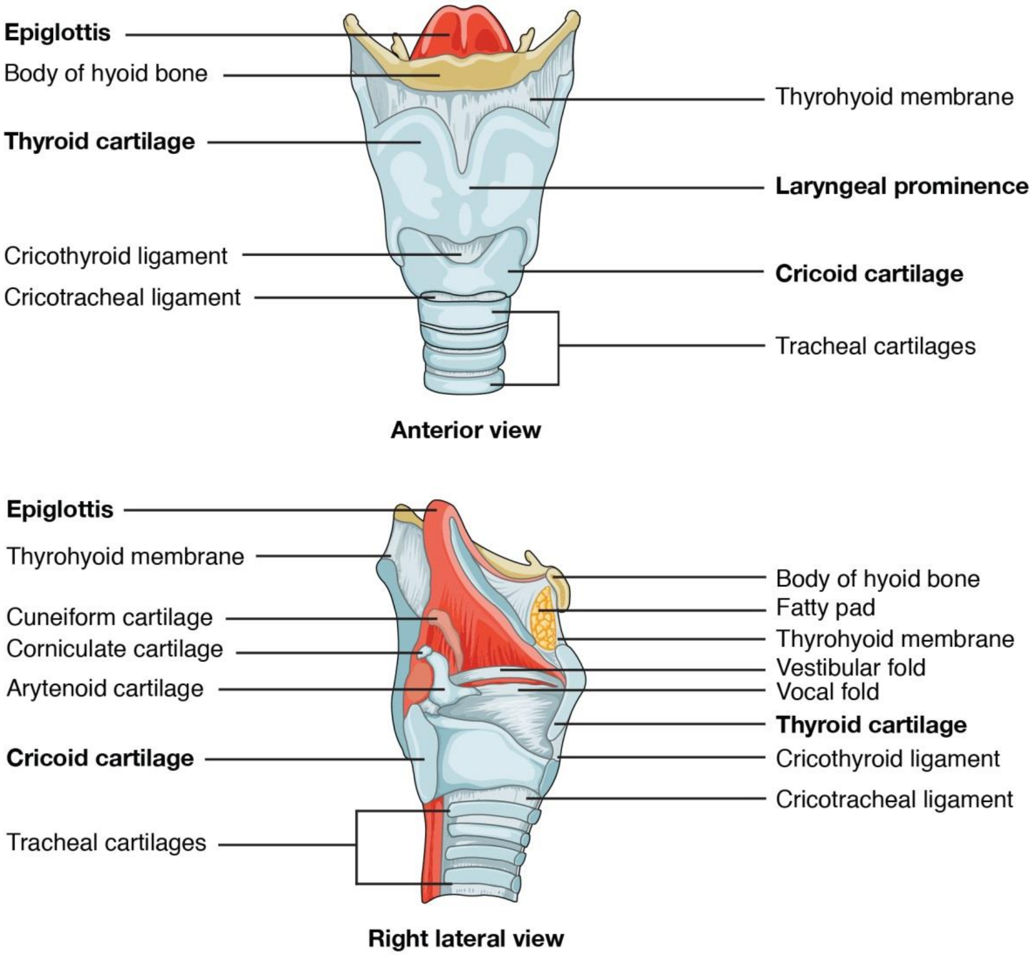


**Figure 22.7 Larynx**

A **true vocal cord** is one of the white, membranous folds attached by muscle to the thyroid and arytenoid cartilages of the larynx on their outer edges. The inner edges of the true vocal cords are free, allowing oscillation to produce sound. The size of the membranous folds of the true vocal cords differs between individuals, producing voices with different pitch ranges. Folds in males tend to be larger than those in females, which create a deeper voice.

The act of swallowing causes the epiglottis to swing downward, closing the opening to the trachea. These movements produce an area for food to pass through, while preventing food and beverages from entering the trachea.

Similar to the nasal cavity and nasopharynx, the top of the larynx contains this specialised epithelium which produce mucus to trap debris and pathogens as they enter the trachea. The cilia beat the mucus upward towards the laryngopharynx, where it can be swallowed down the oesophagus.

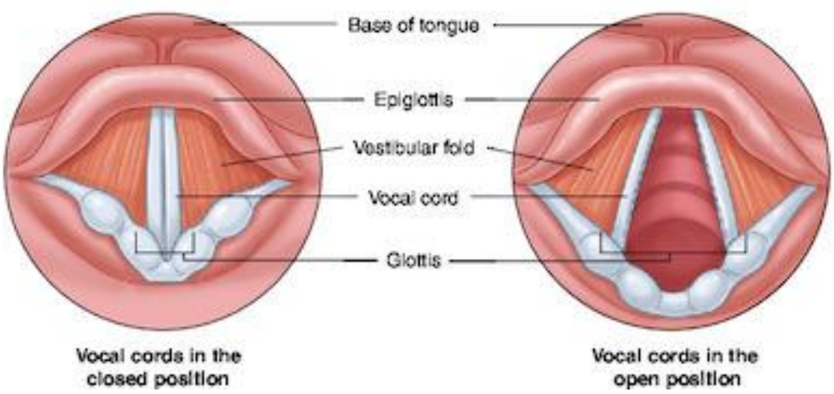


**Figure 22.8 Vocal Cords** The true vocal cords and vestibular folds of the larynx are viewed inferiorly from the laryngopharynx.

### Trachea
The trachea (windpipe) extends from the larynx toward the lungs (Figure 22.9a). The **trachea** is formed by 16 to 20 stacked, C-shaped pieces of cartilage that are connected by dense connective tissue. In an adult it is about 12 cm (5 in.) long and 2.5 cm (1 in.) in diameter.
The **trachealis muscle** and elastic connective tissue together form a flexible membrane that closes the rear surface of the trachea, connecting the C-shaped cartilages. The membrane allows the trachea to stretch and expand slightly during inhalation and exhalation, whereas the rings of cartilage provide structural support and prevent the trachea from collapsing. In addition, the trachealis muscle can be contracted to force air through the trachea during exhalation.

### Bronchial Tree
The trachea branches into the right and left primary **bronchi** at the carina. The carina is a raised structure that contains specialised nervous tissue that induces violent coughing if a foreign body, such as food, is present. Rings of cartilage, similar to those of the trachea, support the structure of the bronchi and prevent their collapse.

The bronchi continue to branch into bronchial a tree. A **bronchial tree** (or respiratory tree) is the collective term used for these multiple-branched bronchi. The main function of the bronchi, like other conducting zone structures, is to provide a passageway for air to move into and out of each lung. In addition, the mucous membrane traps debris and pathogens.

A **bronchiole** branches from the tertiary bronchi. Bronchioles, which are about 1 mm in diameter, further branch until they become the tiny terminal bronchioles, which lead to the structures of gas exchange. There are more than 1000 terminal bronchioles in each lung. The muscular walls of the bronchioles do not contain cartilage like those of the bronchi. This muscular wall can change the size of the tubing to increase or decrease airflow through the tube.

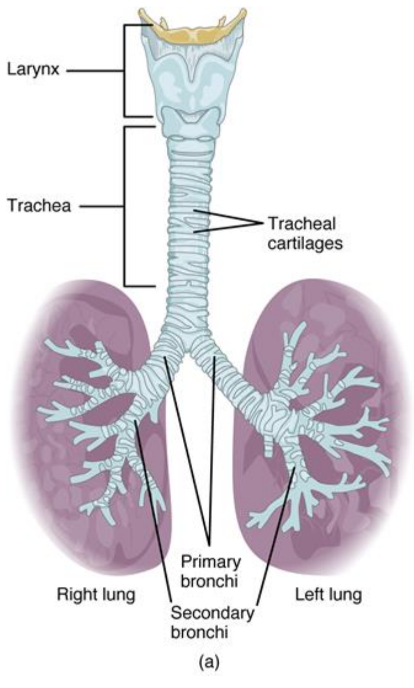


**Figure 22.9 Trachea** The tracheal tube is formed by stacked, C-shaped pieces of hyaline cartilage.

## Respiratory Zone
In contrast to the conducting zone, the respiratory zone includes structures that are directly involved in gas exchange. The respiratory zone begins where the terminal bronchioles join a **respiratory bronchiole**, the smallest type of bronchiole (Figure 22.10), which then leads to an alveolar duct, opening into a cluster of alveoli.

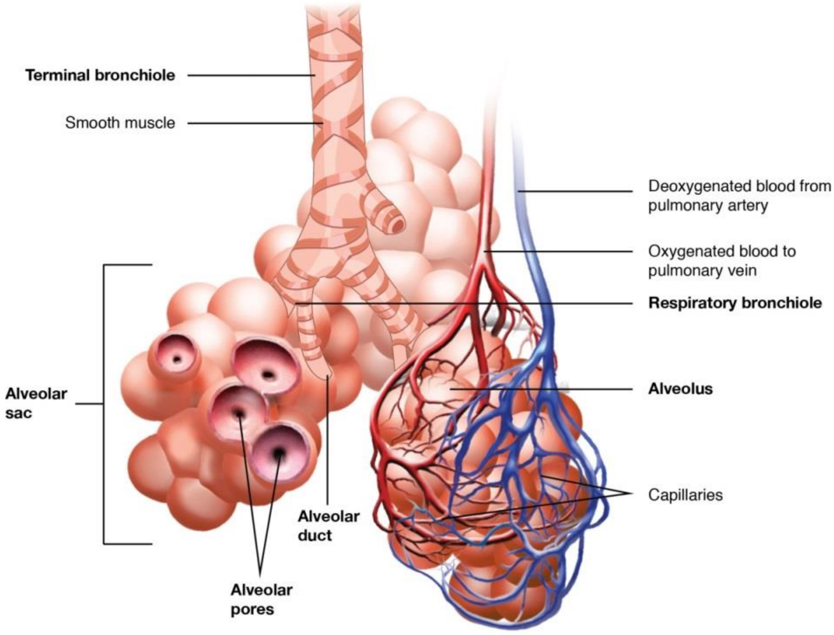


**Figure 22.10** Respiratory Zone Bronchioles lead to alveolar sacs in the respiratory zone, where gas exchange occurs.

## Alveoli

An **alveolar duct** is a tube composed of smooth muscle and connective tissue, which opens into a cluster of alveoli. Each lung holds approximately 1.5 to 2 million of them. Each alveolar duct then divides into two or three alveolar sacs.

An **alveolus** is one of the many small, grape-like sacs that are attached to the alveolar ducts.

An **alveolar sac** is a cluster of many individual alveoli that are responsible for gas exchange. An alveolus is approximately 0.2 mm in diameter (width of 2 human hairs) with elastic walls that allow the alveolus to stretch during air intake, which greatly increases the surface area available for gas exchange. Alveoli are connected to their neighbours by **alveolar pores**, which help maintain equal air pressure throughout the alveoli and lung (Figure 22.11).

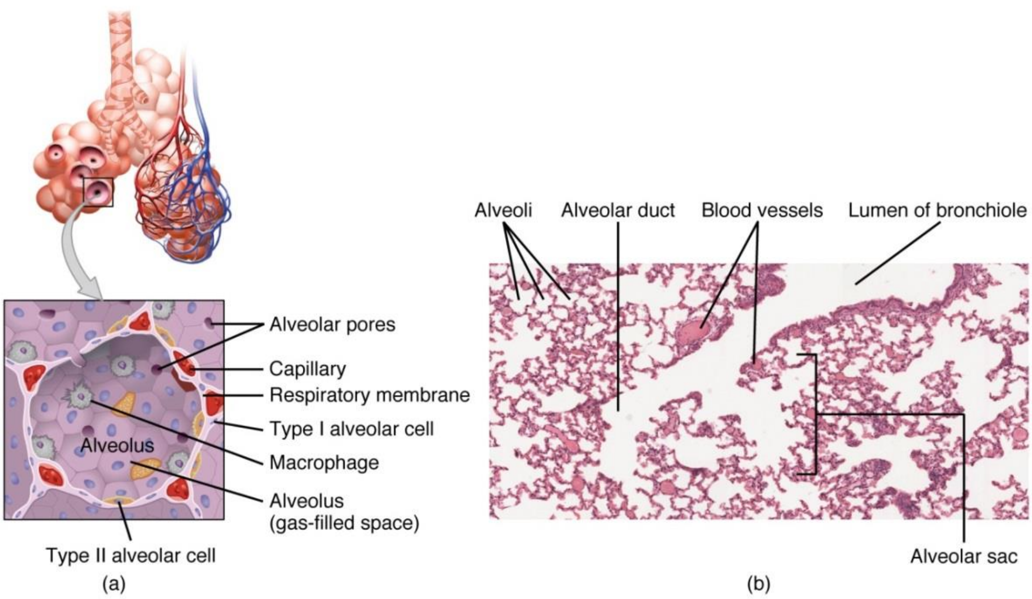


**Figure 22.11 Structures of the Respiratory Zone** (a) The alveolus is responsible for gas exchange.
(b) A micrograph shows the alveolar structures within lung tissue. LM × 178. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

The alveolar wall consists of three major cell types: type I alveolar cells, type II alveolar cells, and alveolar macrophages. **Type I alveolar**, which constitute up to 97 percent of the alveolar surface area, are highly permeable to gases. A **type II alveolar cell** is interspersed among the type I cells and secretes **pulmonary surfactant**, a substance that reduces the surface tension of the alveoli. Roaming around the alveolar wall is the **alveolar macrophage**, a cell of the immune system that removes debris and pathogens that have reached the alveoli.

The single layer of flat cells (squamous epithelium) formed by type I alveolar cells is attached to a thin, elastic basement membrane. This epithelium is extremely thin and borders the capillaries. Taken together, the alveoli and capillary membranes form a **respiratory membrane** that is approximately 0.5 µm (0.0005mm) thick. The respiratory membrane allows gases to cross by simple diffusion, allowing oxygen to be picked up by the blood for transport and $CO_2$ to be released into the air of the alveoli.

## DISEASES OF THE...

### Respiratory System: Asthma

Asthma is common condition that affects the lungs in both adults and children. Approximately 8.2 percent of adults (18.7 million) and 9.4 percent of children (7 million) in the United States suffer from asthma. In addition, asthma is the most frequent cause of hospitalisation in children.

Asthma is a chronic disease characterised by inflammation and oedema of the airway, and bronchospasms (that is, constriction of the bronchioles), which can inhibit air from entering the lungs. In addition, excessive mucus secretion can occur, which further contributes to airway occlusion (Figure 22.12). Cells of the immune systemmay also be involved in infiltrating the walls of the bronchi and bronchioles.

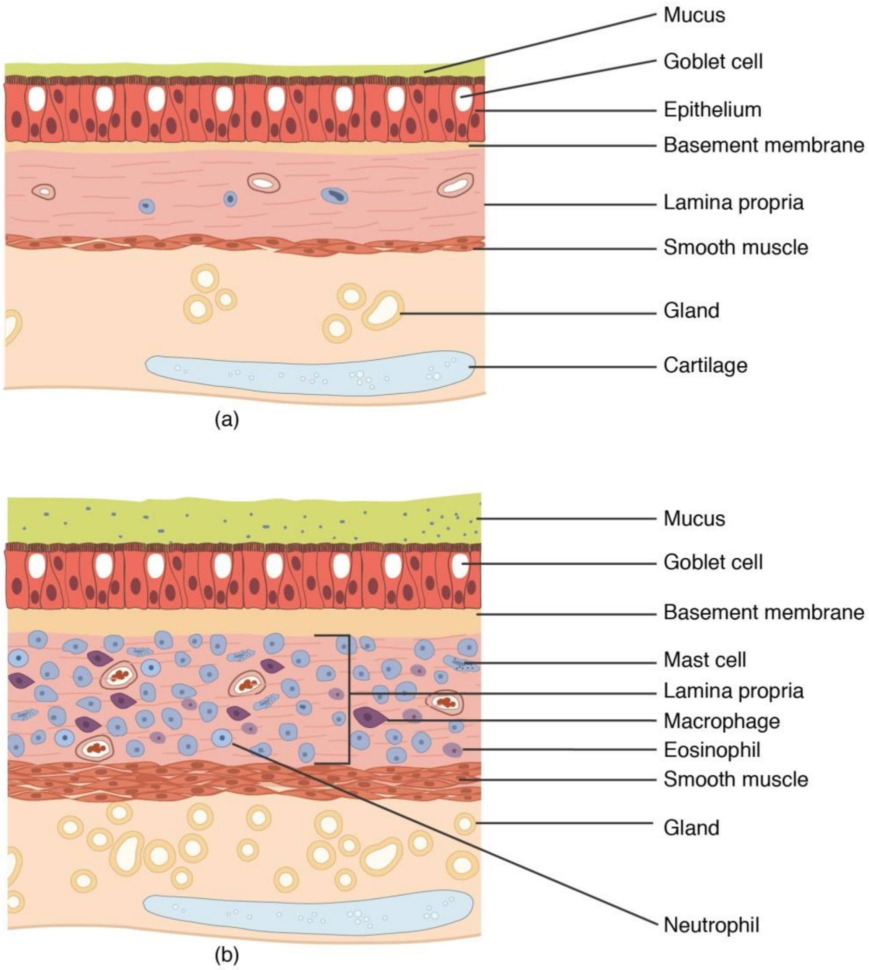


**Figure 22.12 Normal and Bronchial Asthma Tissues** (a) Normal lung tissue does not have the characteristics of lung tissue during (b) an asthma attack, which include thickened mucosa, increased mucus-producing goblet cells, and eosinophil infiltrates.

Bronchospasms occur periodically and lead to an "asthma attack." An attack may be triggered by environmental factors such as dust, pollen, pet hair, or dander, changes in the weather, mould, tobacco smoke, and respiratory infections, or by exercise and stress.

Symptoms of an asthma attack involve coughing, shortness of breath, wheezing, and tightness of the chest. Symptoms of a severe asthma attack that requires immediate medical attention would include difficulty breathing that results in blue (cyanotic) lips or face, confusion, drowsiness, a rapid pulse, sweating, and severe anxiety. The severity of the condition, frequency of attacks, and identified triggers influence the type of medication that an individual may require.

Longer-term treatments are used for those with more severe asthma. Short-term, fast-acting drugs that are used to treat an asthma attack are typically administered via an inhaler. For young children or individuals who have difficulty using an inhaler, asthma medications can be administered via a nebulizer.

In many cases, the underlying cause of the condition is unknown. However, recent research has demonstrated that certain viruses, such as human rhinovirus C (HRVC), and the bacteria *Mycoplasma pneumoniae* and *Chlamydia pneumoniae* that are contracted in early childhood, may contribute to the development of many cases of asthma.

## The Lungs

A major organ of the respiratory system, each **lung** houses structures of both the conducting and respiratory zones. The main function of the lungs is to perform the exchange of oxygen and carbon dioxide with air from the atmosphere. To this end, the lungs exchange respiratory gases across a very large epithelial surface area—about 70 square meters—that is highly permeable to gases.

### Gross Anatomy of the Lungs

The lungs are in the sealed-off thoracic cavity. The rib cage forms the top and sides of the cavity and the diaphragm forms the bottom. The diaphragm is the flat, dome-shaped muscle located at the base of the lungs and thoracic cavity. The lungs are pyramid-shaped, paired organs that are connected to the trachea by the right and left bronchi.

The lungs are enclosed by the pleurae, which are attached to the mediastinum (a membranous partition between the lungs). The right lung is shorter and wider than the left lung, and the left lung occupies a smaller volume than the right. This is partly due to the **cardiac notch** which is an indentation on the surface of the left lung, and it allows space for the heart (Figure 22.13a).

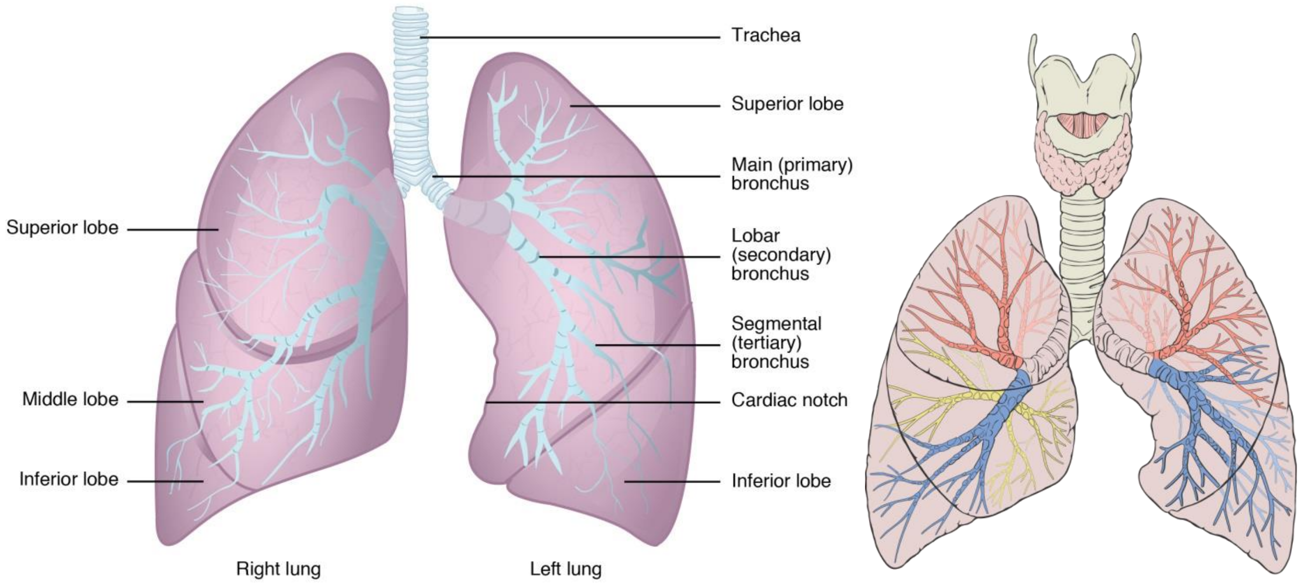


**Figure 22.13a Gross Anatomy of the Lungs and 22.13b** the human lungs with the respiratory tract visible, and different colours for each lobe

Each lung is composed of smaller units called lobes. The right lung consists of three lobes: the superior, middle, and inferior lobes. The left lung consists of two lobes: the superior and inferior lobes. A bronchopulmonary segment is a division of a lobe, and each lobe houses multiple bronchopulmonary segments. Each segment receives air from its own tertiary bronchus and is supplied with blood by its own artery.

Some diseases of the lungs typically affect one or more bronchopulmonary segments, and in some cases, the diseased segments can be surgically removed with little influence on neighbouring segments. A pulmonary lobule is a subdivision formed as the bronchi branch into bronchioles. Each lobule receives its own large bronchiole that has multiple branches.

**Blood Supply and Nervous Innervation of the Lungs**
The blood supply of the lungs plays an important role in gas exchange and also serves as a transport system for gases throughout the body. In addition, innervation by the both the parasympathetic and sympathetic nervous systems provides an important level of control through dilation and constriction of the airway.

**Blood Supply**
The major function of the lungs is to perform gas exchange, which requires deoxygenated blood from the pulmonary circulation. This blood supply travels to the lungs where erythrocytes, also known as red blood cells, pick up oxygen to be transported to tissues throughout the body.

The main pulmonary artery begins at the base of the heart's right ventricle and carries deoxygenated blood to the alveoli (Figure 22.14). The pulmonary artery branches multiple times as it follows the bronchi, and each branch becomes progressively smaller in diameter. One arteriole and an accompanying venule supply and drain one pulmonary lobule. As they near the alveoli, the pulmonary arteries become the pulmonary capillary network. The pulmonary capillary network consists of tiny vessels with very thin walls that lack smooth muscle fibres.

The capillaries branch and follow the bronchioles and structure of the alveoli. It is at this point that the capillary wall meets the alveolar wall, creating the respiratory membrane. Once the blood is oxygenated, it drains from the alveoli by way of multiple pulmonary veins, which exit the lungs through the **hilum**. The hilum is where the bronchi, arteries, veins, and nerves enter and exit the lungs.

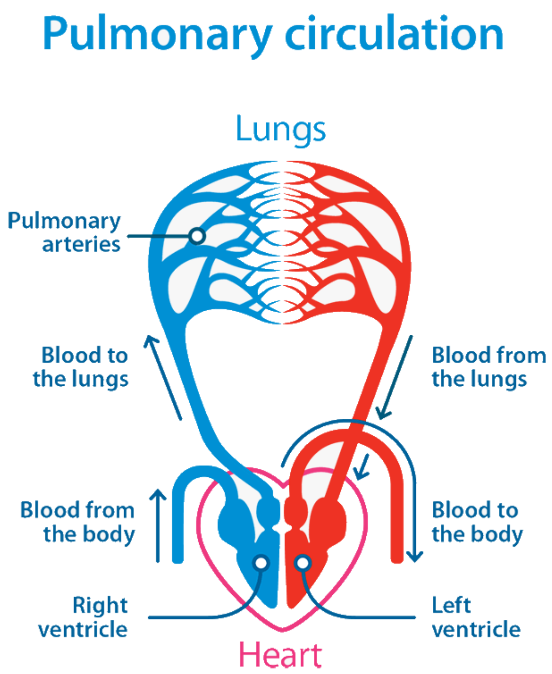


**Figure 22.14 Simplified Pulmonary Circulation**

**Nervous Innervation**
Dilation and constriction of the airway are achieved through nervous control by the parasympathetic and sympathetic nervous systems. The parasympathetic system causes **bronchoconstriction**, whereas the sympathetic nervous system stimulates **bronchodilation**. Reflexes such as coughing, and the ability of the lungs to regulate oxygen and carbon dioxide levels, also result from this autonomic nervous system control.

**Pleura of the Lungs**
Each lung is enclosed within a cavity that is surrounded by the pleura. The pleura (plural = pleurae) is a membrane that surrounds the lung. The right and left pleurae, which enclose the right and left lungs, respectively, are separated by the mediastinum. The pleurae consist of two layers. The **visceral pleura** is the inner layer and the **parietal pleura** (Figure 22.15) is the outer layer. The **pleural cavity** is the space between the visceral and parietal layers.

The pleurae perform two major functions: They produce pleural fluid and create cavities that separate the major organs. **Pleural fluid** is secreted from both pleural layers and acts to lubricate their surfaces. This acts as a lubricant and allows the pleurae to slide effortlessly against each other during breathing, and creates a surface tension that helps maintain the position of the lungs against the thoracic wall. This adhesive characteristic of the pleural fluid causes the lungs to enlarge when the thoracic wall expands during ventilation, allowing the lungs to fill with air.

The pleurae also create a division between major organs that prevents interference due to the movement of the organs, while preventing the spread of infection.

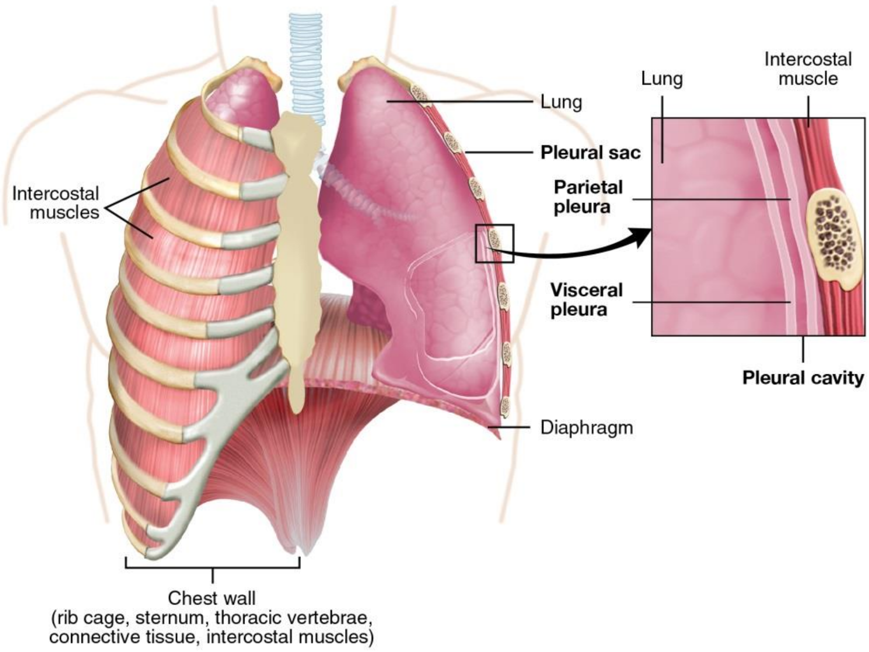


**Figure 22.15 Parietal and Visceral Pleurae of the Lungs**

**EVERYDAY CONNECTION…**
**The Effects of Second-Hand Tobacco Smoke**
The burning of a tobacco cigarette creates multiple chemical compounds that are released through mainstream smoke, which is inhaled by the smoker, and through sidestream smoke, which is the smoke that is given off by the burning cigarette.

Second-hand smoke, which is a combination of sidestream smoke and the mainstream smoke that is exhaled by the smoker, has been demonstrated by numerous scientific studies to cause disease. At least 40 chemicals in sidestream smoke have been identified that negatively impact human health, leading to the development of cancer or other conditions, such as immune system dysfunction, liver toxicity, cardiac arrhythmias, pulmonary oedema, and neurological dysfunction.

Furthermore, second-hand smoke has been found to harbour at least 250 compounds that are known to be toxic, carcinogenic, or both. Some major classes of carcinogens in second-hand smoke are polyaromatic hydrocarbons (PAHs), N-nitrosamines, aromatic amines, formaldehyde, and acetaldehyde.

Tobacco and second-hand smoke are considered to be carcinogenic. Exposure to second-hand smoke can cause lung cancer in individuals who are not tobacco users themselves. It is estimated that the risk of developing lung cancer is increased by up to 30 percent in nonsmokers who live with an individual who smokes in the house, as compared to nonsmokers who are not regularly exposed to second-hand smoke.

Children are especially affected by second-hand smoke. Children who live with an individual who smokes inside the home have a larger number of lower respiratory infections, which are associated with hospitalizations, and higher risk of sudden infant death syndrome (SIDS). Second-hand smoke in the home has also been linked to a greater number of ear infections in children, as well as worsening symptoms of asthma.



This module is based on the OpenStax book which is available for free at http://cnx.org/content/col11496/1.8



This module is based on the OpenStax book which is available for free at http://cnx.org/content/col11496/1.8