Breathing and Exchange of Gases

Objectives

After going through this lesson, the learners will be able to understand the following:

- Respiratory Organs
- Respiratory system of Humans
- The Respiratory Tract
- The Pharynx
- The Larynx

Content Outline

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Introduction

The air that we inhale into our body contains 78.06% Nitrogen (N_2), 20.98% Oxygen (O_2), 0.04% Carbon dioxide (CO_2) and 0.92% other inert constituents such as argon and helium. Oxygen is utilized by the body to indirectly break down nutrient molecules like glucose and to derive energy for performing various activities. Carbon dioxide (CO_2) which is harmful is also released during the above catabolic reactions. It is, therefore, evident that O_2 has to be continuously provided to the cells and CO_2 produced by the cells have to be released out. This process of exchange of O_2 from the atmosphere with CO_2 produced by the cells is called **breathing**, commonly known as **respiration** and the organs responsible for respiration constitute the Respiratory system. Place your hands on your chest; you can feel the chest moving up and down. You know that it is due to breathing. How do we breathe? In this module, we will discuss the Respiratory organs of Humans.

Respiratory Organs

Mechanism of breathing vary among different groups of animals depending mainly on their habitats and levels of organisation. Lower invertebrates like sponges, coelenterates, flatworms, etc., exchange O_2 with CO_2 by simple diffusion over their entire body surface. Earthworms use their moist cuticle and insects have a network of tubes (tracheal tubes) to transport atmospheric air within the body. Special vascularised structures called **gills** are used by most of the aquatic arthropods and molluscs whereas vascularised bags called **lungs** are used by the terrestrial forms for the exchange of gases. Among vertebrates, fishes use gills whereas reptiles, birds and mammals respire through lungs. Amphibians like frogs can respire through their moist skin also. Mammals have a well-developed respiratory system.

Respiratory System of Humans

The primary function of the respiratory system is to allow oxygen from the air to enter the blood and carbon dioxide from the blood to exit into the air. During **inspiration,** or inhalation (breathing in), and **expiration**, or exhalation (breathing out), air is conducted toward or away from the lungs by a series of cavities, tubes, and openings, illustrated in Figure 14.1.

The respiratory system also works with the cardiovascular system to accomplish these four respiratory events:

a) Breathing, the entrance and exit of air into and out of lungs;

b) External respiration, the exchange of gases (oxygen and carbon dioxide) between air and blood;

c) Internal respiration, the exchange of gases between blood and tissue fluid;

d) Transport of gases to and from the lungs and the tissues.

Cellular respiration, which produces ATP, uses the oxygen and produces the carbon dioxide that makes gas exchange with the environment necessary. Without a continuous supply of ATP, the cells cease to function. The four events listed here allow cellular respiration to continue.

The Respiratory Tract

Table 14.1 traces the path of air from the nose to the lungs. As air moves in along the airways, it is cleansed, warmed, and moistened. Cleansing is accomplished by coarse hairs just inside the nostrils and by cilia and mucus in the nasal cavities and the other airways of the respiratory tract. In the nose, the hairs and the cilia act as screening devices. In the trachea and other airways, the cilia beat upward, carrying mucus, dust, and occasional bits of food that "went down the wrong way" into the pharynx, where the accumulation can be swallowed or expectorated. The air is warmed by heat given off by the blood vessels lying close to the surface of the lining of the airways, and it is moistened by the wet surface of these passages. Conversely, as air moves out during expiration, it cools and loses its moisture. As the air cools, it deposits its moisture on the lining of the trachea and the nose, and the nose may even drip as a result of this condensation. The air still retains so much moisture, however, that upon expiration on a cold day, it condenses and forms a small cloud.

Table 14.1 Path of Air

Structure	Description	Function
Upper Respiratory Tract		
Nasal cavitities	Hollow spaces in nose	Filter, warm, and moisten air
Pharynx	Chamber posterior to oral cavity; lies between nasal cavity and larynx	Connection to surrounding regions
Glottis	Opening into larynx	Passage of air into larynx
Larnyx	Cartilaginous organ that houses the vocal cords; voice box	Sound production
Lower Respiratory Tract		
Trachea	Flexible tube that connects larynx with bronchi	Passage of air to bronchi
Bronchi	Paired tubes inferior to the trachea that enter the lungs	Passage of air to lungs
Bronchioles	Branched tubes that lead from bronchi to alveoli	Passage of air to each alveolus
Lungs	Soft, cone-shaped organs that occupy lateral portions of thoracic cavity	Gas exchange

The Nose

The **nose**, a prominent feature of the face, is the only external portion of the respiratory system. Air enters the nose through external openings called **nostrils**. The nose contains two **nasal cavities**, which are narrow canals separated from one another by a septum composed of bone and cartilage (Fig. 14.2).

Mucous membrane lines the nasal cavities. The nasal **conchae** are bony ridges that project laterally into the nasal cavity. They increase the surface area for moistening and warming air during inhalation and for trapping water droplets during exhalation. Odor receptors are on the cilia of cells located high in the recesses of the nasal cavities.

The tear (lacrimal) glands drain into the nasal cavities by way of tear ducts. For this reason, crying produces a runny nose. The nasal cavities also communicate with the **paranasal sinuses**, air-filled spaces that reduce the weight of the skull and act as resonating chambers for the voice. If the ducts leading from the sinuses become inflamed, fluid may accumulate, causing a sinus headache. The nasal cavities are separated from the oral cavity by a partition called the palate, which has two portions. Anteriorly, the hard palate is supported by bone, and posteriorly the soft palate is not so supported.

The Pharynx

The **pharynx** is a funnel-shaped passageway that connects the nasal and oral cavities to the larynx. Consequently, the pharynx, commonly referred to as the "throat," has three parts: the nasopharynx, where the nasal cavities open posterior to the soft palate; the oropharynx, where the oral cavity joins the pharynx; and the laryngopharynx, which opens into the larynx. The soft palate has a soft extension called the uvula that can be seen projecting into the oropharynx.

The tonsils form a protective ring at the junction of the oral cavity and the pharynx. Being lymphatic tissue, the tonsils contain lymphocytes that protect against invasion of inhaled pathogens. Here, both B cells and T cells are prepared to respond to antigens that may subsequently invade internal tissues and fluids. In this way, the respiratory tract assists the immune system in maintaining homeostasis.In the pharynx, the air passage and the food passage cross because the larynx, which receives air, is anterior to the esophagus, which receives food. The larynx lies at the top of the trachea. The larynx and trachea are normally open, allowing air to pass, but the esophagus is normally closed and opens only when a person swallows.

The Larynx

The **larynx** is a cartilaginous structure that serves as a passageway for air between the pharynx and the trachea. The larynx can be pictured as a triangular box whose apex, the

Adam's apple, is located at the anterior of the neck. The larynx is called the voice box because it houses the vocal cords. The **vocal cords** are mucosal folds supported by elastic ligaments, and the slit between the vocal cords is an opening called the **glottis** (Fig. 14.3). When air is expelled past the vocal cords through the glottis, the vocal cords vibrate, producing sound. At the time of puberty, the growth of the larynx and the vocal cords is much more rapid and accentuated in the male than in the female, causing the male to have a more prominent Adam's apple and a deeper voice. The voice "breaks" in the young male due to his inability to control the longer vocal cords. These changes cause the lower pitch of the voice in males.

The high or low pitch of the voice is regulated when speaking and singing by changing the tension on the vocal cords. The greater the tension, as when the glottis becomes more narrow, the higher the pitch. When the vocal cords relax, the glottis is wider, and the pitch is lower (Fig. 14.3b). The loudness, or intensity, of the voice depends upon the amplitude of the vibrations—that is, the degree to which the vocal cords vibrate. When food is swallowed, the larynx moves upward against the **epiglottis,** a flap of tissue that prevents food from passing through the glottis into the larynx. You can detect this movement by placing your hand gently on your larynx and swallowing.

The Trachea

The **trachea,** commonly called the windpipe, is a tube connecting the larynx to the primary bronchi. The trachea lies ventral to the esophagus and is held open by C-shaped cartilaginous rings. The open part of the C-shaped rings faces the esophagus, and this allows the esophagus to expand when swallowing. The mucosa that lines the trachea has a layer of pseudostratified ciliated columnar epithelium. (Pseudostratified means that while the epithelium appears to be layered, actually each cell touches the basement membrane.) The cilia that project from the epithelium keep the lungs clean by sweeping mucus, produced by goblet cells, and debris toward the pharynx: Smoking is known to destroy these cilia, and consequently the soot in cigarette smoke collects in the lungs. Smoking is discussed more fully in the Medical Focus on page 289. If the trachea is blocked because of illness or the accidental swallowing of a foreign object, it is possible to insert a breathing tube by way of an incision made in the trachea. This tube acts as an artificial air intake and exhaust duct. The operation is called a **tracheostomy**.

The Bronchial Tree

The trachea divides into right and left primary bronchi (sing., **bronchus**), which lead into the right and left lungs (see Fig. 14.1). The bronchi branch into a great number of secondary bronchi that eventually lead to **bronchioles**. The bronchi resemble the trachea in structure, but as the bronchial tubes divide and subdivide, their walls become thinner, and the small rings of cartilage are no longer present. During an asthma attack, the smooth muscle of the bronchioles contracts, causing bronchiolar constriction and characteristic wheezing. Each bronchiole leads to an elongated space enclosed by a multitude of air pockets, or sacs, called alveoli (sing., **alveolus**). The components of the bronchial tree beyond the primary bronchi, including the alveoli, compose the lungs.

The Lungs

The **lungs** are paired, cone-shaped organs that occupy the thoracic cavity except for the mediastinum, a central area that contains the primary bronchi, the heart, and other organs. The right lung has three lobes, and the left lung has two lobes, allowing room for the heart whose apex points left. A lobe is further divided into lobules, and each lobule has a bronchiole serving many alveoli. The apex is the superior narrow portion of a lung, and the base is the inferior broad portion that curves to fit the dome-shaped diaphragm, the muscle that separates the thoracic cavity from the abdominal cavity. The lateral surfaces of the lungs follow the contours of the ribs in the thoracic cavity.

Each lung is enclosed by a double layer of serous membrane called the **pleura.** The visceral pleura adheres to the surface of the lung, while the parietal pleura lines the thoracic cavity. The pleura produces a lubricating serous fluid that allows its two layers to slide against one another. **Surface tension** is the tendency for water molecules to cling to each other (due to hydrogen bonding between the molecules) and to form a droplet. Surface tension holds the two pleural layers together when the lungs recoil during expiration.

The Alveoli

With each inhalation, air passes by way of the bronchial tree to the alveoli. An alveolar sac is made up of simple squamous epithelium surrounded by blood capillaries. Gas exchange occurs between the air in the alveoli and the blood in the capillaries (Fig. 14.4). Oxygen diffuses across the alveolar and capillary walls to enter the bloodstream, while carbon dioxide diffuses from the blood across these walls to enter the alveoli. The alveoli must stay open to

receive the inhaled air if gas exchange is to occur. Gas exchange takes place across moist cellular membranes, and yet the surface tension of water lining the alveoli is capable of causing them to close up. The alveoli are lined with a **surfactant**, a film of lipoprotein that lowers the surface tension and prevents them from closing. The lungs collapse in some newborn babies, especially premature infants, who lack this film. The condition, called **infant respiratory distress syndrome**, is now treatable by surfactant replacement therapy.

Respiratory Membrane Gas exchange occurs very rapidly because of the characteristics of the so-called respiratory membrane (Fig. 14.5). The **respiratory membrane** consists of the juxtaposed alveolar epithelium and the capillary endothelium. At times, their basement membranes are fused, meaning that very little tissue fluid separates the two portions of the respiratory membrane and they are indeed one membrane. This membrane is extremely thin—only 0.2–0.6 μm thick. The total surface area of the respiratory membrane is the same as the area of the alveoli, namely 50–70 m2. The blood that enters the many pulmonary capillaries spreads thin. The red blood cells within the capillaries are pressed up against the narrow capillary walls, and little plasma is present. This too facilitates the speed of gas exchange during external respiration.

Disorders of Respiratory System

The respiratory tract is constantly exposed to environmental air. The quality of this air can affect our health. The presence of a disease means that homeostasis is threatened, and if the condition is not brought under control, death is possible.

Upper Respiratory Tract Infections

The upper respiratory tract consists of the nasal cavities, the pharynx, and the larynx. Upper respiratory infections (URI) can spread from the nasal cavities to the sinuses, middle ears, and larynx. Viral infections sometimes lead to secondary bacterial infections. What we call “strep throat” is a primary bacterial infection caused by Streptococcus pyogenes that can lead to a generalized upper respiratory infection and even a systemi (affecting the body as a whole) infection. Although antibiotics have no effect on viral infections, they are successfully used to treat most bacterial infections, including strep throat. The symptoms of strep throat are severe sore throat, high fever, and white patches on a dark red throat.

Sinusitis

Sinusitis is an infection of the cranial sinuses, the cavities within the facial skeleton that drain into the nasal cavities. Only about 1-3% of upper respiratory infections are accompanied by sinusitis. Sinusitis develops when nasal congestion blocks the tiny openings leading to the sinuses. Symptoms include postnasal discharge as well as facial pain that worsens when the patient bends forward. Pain and tenderness usually occur over the lower forehead or over the cheeks. If the latter, toothache is also a complaint. Successful treatment depends on restoring proper drainage of the sinuses. Even a hot shower and sleeping upright can be helpful. Otherwise, spray decongestants are preferred over oral antihistamines, which thicken rather than liquefy the material trapped in the sinuses.

Otitis Media

Otitis media is a bacterial infection of the middle ear. The middle ear is not a part of the respiratory tract, but this infection is considered here because it is a complication often seen in children who have a nasal infection. Infection can spread by way of the **auditory (eustachian) tube** that leads from the nasopharynx to the middle ear. Pain is the primary symptom of a middle ear infection. A sense of fullness, hearing loss, vertigo (dizziness), and fever may also be present.

Antibiotics almost always bring about a full recovery, and recurrence is probably due to a new infection. Tubes (called tympanostomy tubes) are sometimes placed in the eardrums of children with multiple recurrences to help prevent the build-up of pressure in the middle ear and the possibility of hearing loss. Normally, the tubes fall out with time.

Tonsillitis

Tonsillitis occurs when the **tonsils,** masses of lymphatic tissue in the pharynx, become inflamed and enlarged. The tonsils in the posterior wall of the nasopharynx are often called adenoids. If tonsillitis occurs frequently and enlargement makes breathing difficult, the tonsils can be removed surgically in a **tonsillectomy**. Fewer tonsillectomies are performed today than in the past because we now know that the tonsils remove many of the pathogens that enter the pharynx; therefore, they are a first line of defense against invasion of the body.

Laryngitis

Laryngitis is an infection of the larynx with accompanying hoarseness leading to the inability to talk in an audible voice. Usually, laryngitis disappears with treatment of the upper

respiratory infection. Persistent hoarseness without the presence of an upper respiratory infection is one of the warning signs of cancer, and therefore should be looked into by a physician.

Lower Respiratory Tract Disorders

Lower respiratory tract disorders include infections, restrictive pulmonary disorders, obstructive pulmonary disorders, and lung cancer.

Lower Respiratory Infections

Acute bronchitis, pneumonia, and tuberculosis are infections of the lower respiratory tract. **Acute bronchitis** is an infection of the primary and secondary bronchi. Usually, it is preceded by a viral URI that has led to a secondary bacterial infection. Most likely, a nonproductive cough has become a deep cough that expectorates mucus and perhaps pus.

Pneumonia is a viral or bacterial infection of the lungs in which the bronchi and alveoli fill with thick fluid (Fig. 14.10). Most often, it is preceded by influenza. High fever and chills, with headache and chest pain, are symptoms of pneumonia. Rather than being a generalized lung infection, pneumonia may be localized in specific lobules of the lungs; obviously, the more lobules involved, the more serious is the infection. Pneumonia can be caused by a bacterium that is usually held in check but has gained the upper hand due to stress and/or reduced immunity. AIDS patients are subject to a particularly rare form of pneumonia caused by the protozoan Pneumocystis carinii. Pneumonia of this type is almost never seen in individuals with a healthy immune system.

Pulmonary tuberculosis is caused by the tubercle bacillus, a type of bacterium. When tubercle bacilli invade the lung tissue, the cells build a protective capsule about the foreigners, isolating them from the rest of the body. This tiny capsule is called a tubercle. If the resistance of the body is high, the imprisoned organisms die, but if the resistance is low, the organisms eventually can be liberated. If a chest X ray detects active tubercles, the individual is put on appropriate drug therapy to ensure the localization of the disease and the eventual destruction of any live bacteria. It is possible to tell if a person has ever been exposed to tuberculosis with a test in which a highly diluted extract of the bacillus is injected into the skin of the patient. A person who has never been in contact with the tubercle bacillus

shows no reaction, but one who has had or is fighting an infection shows an area of inflammation that peaks in about 48 hours.

Restrictive Pulmonary Disorders

In restrictive pulmonary disorders, vital capacity is reduced because the lungs have lost their elasticity. Inhaling particles such as silica (sand), coal dust, asbestos, and, now it seems, fiberglass can lead to **pulmonary fibrosis**, a condition in which fibrous connective tissue builds up in the lungs. The lungs cannot inflate properly and are always tending toward deflation.

Breathing asbestos is also associated with the development of cancer. Because asbestos was formerly used widely as a fireproofing and insulating agent, unwarranted exposure has occurred. It has been projected that two million deaths caused by asbestos exposure—mostly in the workplace—will occur in the United States between 1990 and 2020.

Obstructive Pulmonary Disorders

In obstructive pulmonary disorders, air does not flow freely in the airways, and the time it takes to inhale or exhale maximally is greatly increased. Several disorders, including chronic bronchitis, emphysema, and asthma, are referred to as chronic obstructive pulmonary disorders (COPD) because they tend to recur.

In **chronic bronchitis**, the airways are inflamed and filled with mucus. A cough that brings up mucus is common. The bronchi have undergone degenerative changes, including the loss of cilia and their normal cleansing action. Under these conditions, an infection is more likely to occur. Smoking cigarettes and cigars is the most frequent cause of chronic bronchitis. Exposure to other pollutants can also cause chronic bronchitis.

Emphysema is a chronic and incurable disorder in which the alveoli are distended and their walls damaged so that the surface area available for gas exchange is reduced. Emphysema is often preceded by chronic bronchitis. Air trapped in the lungs leads to alveolar damage and a noticeable ballooning of the chest. The elastic recoil of the lungs is reduced, so not only are the airways narrowed, but the driving force behind expiration is also reduced. The victim is breathless and may have a cough. Because the surface area for gas exchange is reduced, less oxygen reaches the heart and the brain. Even so, the heart works furiously to force more

blood through the lungs, and an increased workload on the heart can result. Lack of oxygen to the brain can make the person feel depressed, sluggish, and irritable. Before therapy can begin, the patient must stop smoking. Then, exercise, drug therapy, supplemental oxygen, and surgery (see the What's New reading on page 280) may relieve the symptoms and possibly slow the progression of emphysema.

Asthma is a disease of the bronchi and bronchioles that is marked by wheezing, breathlessness, and sometimes a cough and excretion of mucus. The airways are unusually sensitive to specific irritants, which can include a wide range of allergens such as pollen, animal dander, dust, cigarette smoke, and industrial fumes. Even cold air can be an irritant. When exposed to the irritant, the smooth muscle in the bronchioles undergoes spasms. It now appears that chemical mediators given off by immune cells in the bronchioles cause the spasms. Most asthma patients have some degree of bronchial inflammation that reduces the diameter of the airways and contributes to the seriousness of an attack. Asthma is not curable, but it is treatable. Special inhalers can control the inflammation and hopefully prevent an attack, while other types of inhalers can stop the muscle spasms should an attack occur.

Lung Cancer used to be more prevalent in men than in women, but recently it has surpassed breast cancer as a cause of death in women. The recent increase in the incidence of lung cancer in women is directly correlated to increased numbers of women who smoke. Autopsies on smokers have revealed the progressive steps by which the most common form of lung cancer develops. The first event appears to be thickening and callusing of the cells lining the primary bronchi. (Callusing occurs whenever cells are exposed to irritants). Then cilia are lost, making it impossible to prevent dust and dirt from settling in the lungs. Following this, cells with a typical nuclei appear in the callused lining. A tumor consisting of disordered cells with atypical nuclei is considered cancer in situ (at one location) (Fig. 14.11). A final step occurs when some of these cells break loose and penetrate other tissues, a process called metastasis. Now, the cancer has spread. The original tumor may grow until a bronchus is blocked, cutting off the supply of air to that lung. The entire lung then collapses, the secretions trapped in the lung spaces become infected, and pneumonia or a lung abscess (localized area of pus) results. The only treatment that offers a possibility of cure is to remove a lobe or the whole lung before metastasis has had time to occur. This operation is called **pneumonectomy**. If the cancer has spread, chemotherapy and radiation are also required.

The Medical Focus on page 289 lists the various illnesses, including cancer, that are apt to occur when a person smokes.

Current research indicates that passive smoking—exposure to smoke created by others who are smoking—can also cause lung cancer and other illnesses associated with smoking. If a person stops voluntary smoking and avoids passive smoking, and if the body tissues are not already cancerous, they may return to normal over time.