UNIT ONE: OVERVIEW OF PULMONARY ANATOMY AND PHYSIOLOGY

A. The Respiratory System

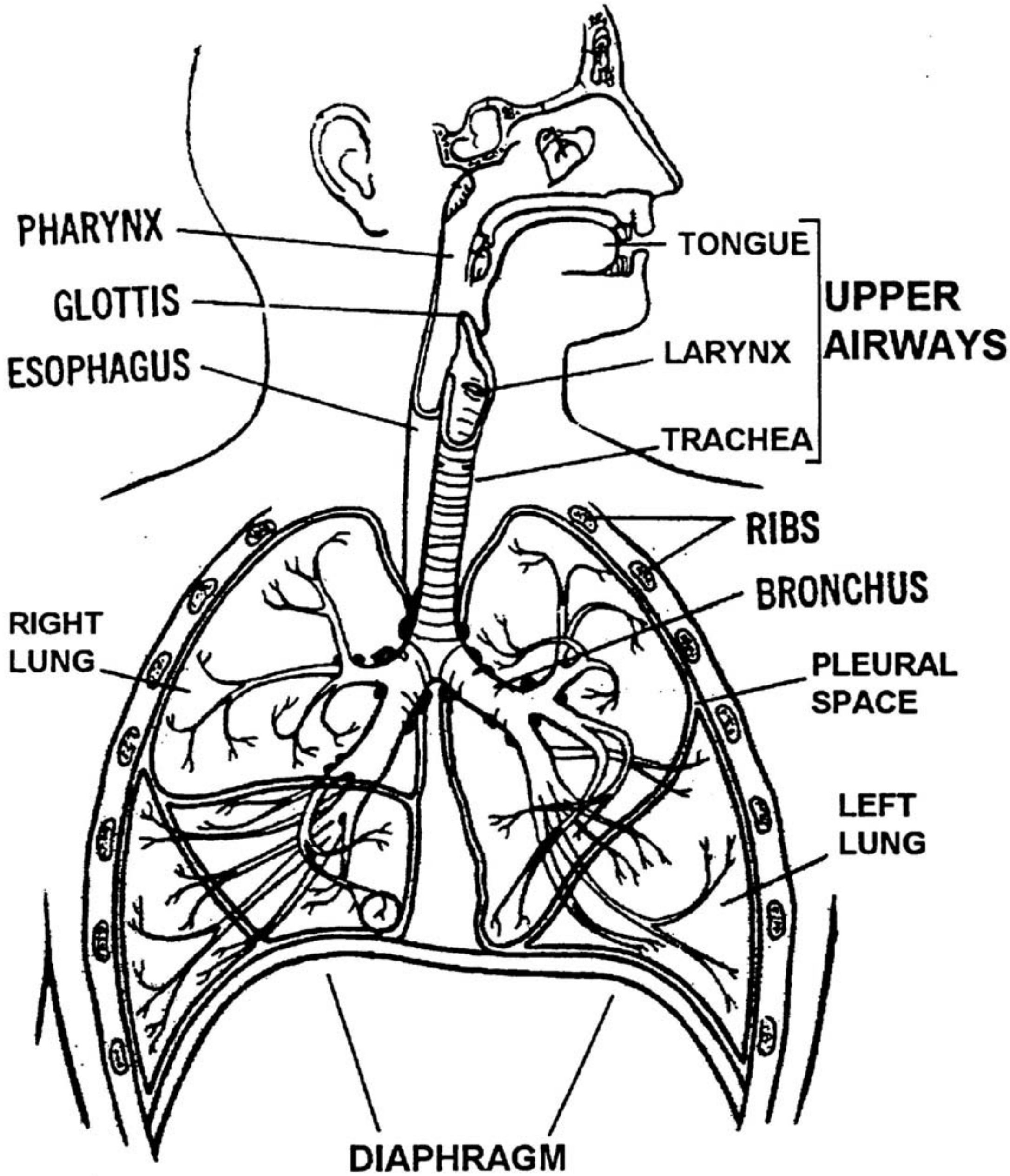
A person can live for weeks without food and a few days without water but only a few minutes without oxygen. Every cell in the body needs a constant supply of oxygen to produce energy to grow, repair or replace itself, and maintain vital functions. The oxygen must be provided to the cells in a way that they can use. It must be brought into the body as air that is cleaned, cooled or heated, humidified, and delivered in the right amounts.

The respiratory system is the body's link to this supply of life-giving oxygen. It includes the diaphragm and chest muscles, the nose and mouth, the pharynx and trachea, the bronchial tree, and the lungs, each of which is discussed below. (See **Figure 1-1. The Respiratory System**.) The bloodstream, the heart, and the brain are also involved. The bloodstream takes oxygen from the lungs to the rest of the body and returns carbon dioxide to them to be removed. The heart creates the force to move the blood at the right speed and pressure throughout the body. The smooth functioning of the entire system is directed by the brain and the autonomic nervous system.

A person at rest breathes about 6 liters of air a minute. Heavy exercise can increase the amount to over 75 liters per minute (3). During an 8-hour work day of moderate activity, the amount of air breathed may be as much as 8.5 m^3 (300 cubic feet). The skin, with its surface area of approximately 1.9m^2 (20 sq. ft.) is commonly thought to have the greatest exposure to air of any body part. However, in reality the lungs have the greatest exposure, with a surface area exposed to air of 28 m^2 (300 sq. ft.) at rest and up to 93 m^2 (1,000 sq. ft.) during a deep breath (4).

The respiratory system is susceptible to damage caused by inhaled toxic materials and irritants because the surface area of the lungs exposed to air is so large and the body's need for oxygen so great. The ability of the respiratory system to function properly has a great impact on the body. Disease in any one of its parts can lead to disease or damage to other vital organs. For example, occupational lung disease can also cause heart disease.

FIGURE 1-1. THE RESPIRATORY SYSTEM



From American Lung Association: Occupational Lung Diseases: An Introduction. New York, NY. Macmillan. 1979: pp 10. (5).

B. Mechanics of Respiration

Air containing oxygen enters the body through the nose and mouth. From there it passes through the pharynx or throat on its way to the trachea (windpipe). The trachea divides into two main airways called bronchi upon reaching the lungs; one bronchus serves the right lung and the other the left. The bronchi subdivide several times into smaller bronchi, which then divide into smaller and smaller branches called bronchioles. These bronchi and bronchioles are called the bronchial tree because the subdividing that occurs is similar to the branching of an inverted tree. After a total of about 23 divisions, the bronchioles end at alveolar ducts. At the end of each alveolar duct, are clusters of alveoli (air sacs). The oxygen transported through the respiratory system is finally transferred to the bloodstream at the alveoli. (See **Figure 1-2. Schematic Diagram of the Airway**.)

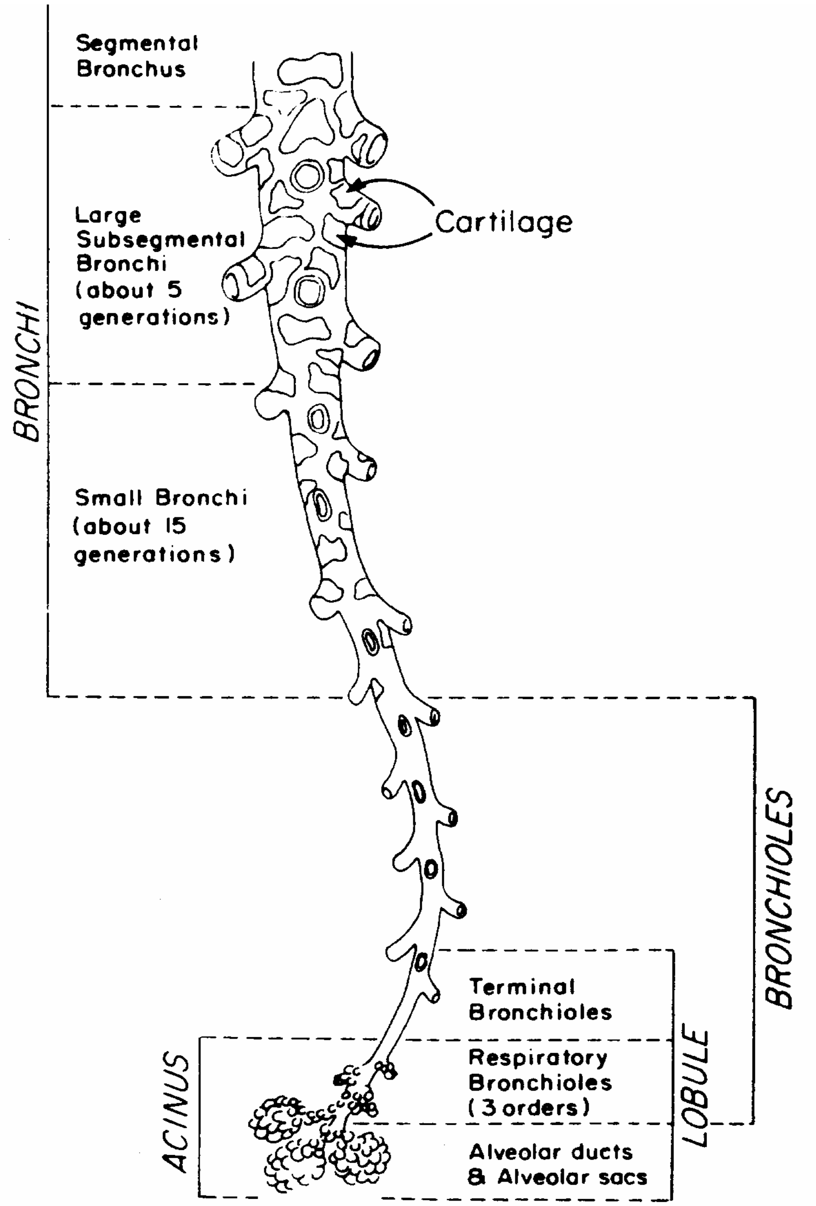
The trachea, main bronchi, and approximately the first dozen divisions of smaller bronchi have either rings or patches of cartilage in their walls that keeps them from collapsing or blocking the flow of air. The remaining bronchioles and the alveoli do not have cartilage and are very elastic. This allows them to respond to pressure changes as the lungs expand and contract.

Blood vessels from the pulmonary arterial system accompany the bronchi and bronchioles. These blood vessels also branch into smaller and smaller units ending with capillaries, which are in direct contact with each alveolus. Gas exchange occurs through this alveolar-capillary membrane as oxygen moves into and carbon dioxide moves out of the bloodstream. (See **Figure 1-3. A Close-Up View of Alveoli and Capillaries**.) Although the 300 million alveoli found in the lungs are microscopic, they have a total surface area equivalent to the size of a tennis court (6).

Diffusing capacity measures the ease with which gas exchange takes place between the alveoli and capillaries. Certain lung diseases affecting the alveoli and capillary walls can interfere with diffusion and reduce the amount of oxygen reaching the bloodstream. Spirometry does not measure diffusing capacity, but it can be measured in a pulmonary function laboratory using an instrument which cost $20,000 to $40,000.

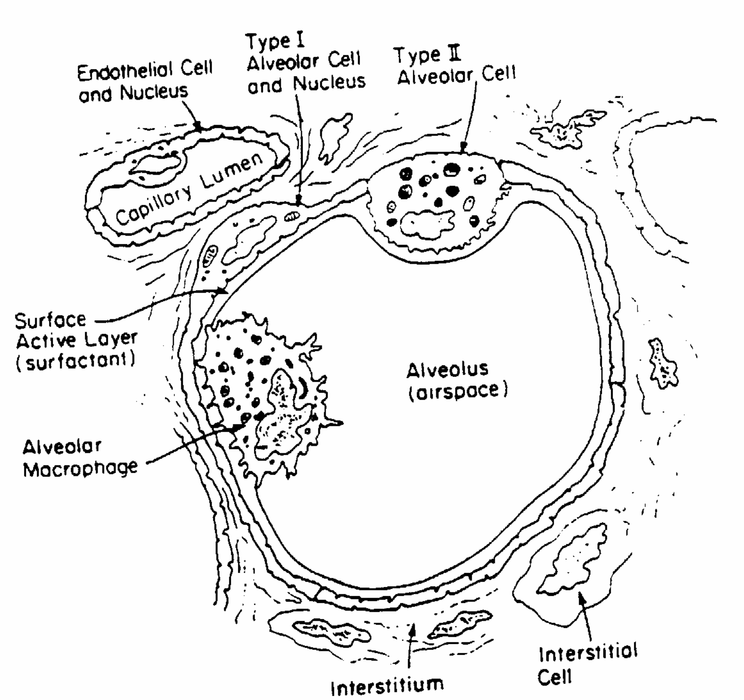
The movement of air into and out of the lungs is called ventilation. The contraction of the inspiratory muscles (principal inspiratory muscle is the **diaphragm**) causes the chest cavity to expand, creating a negative pressure. The resulting flow of air into the lungs is called <u>inspiration</u>. During a maximal inspiration, the diaphragm contracts forcing the abdominal contents downwards and outwards (See Figure 1-1). The external intercostal muscles, found between the ribs, are also involved. These muscles contract and raise the ribs during inspiration, thus increasing the diameter of the chest cavity. In addition to these muscles, the scalene muscle and the sternomastoid muscle in the neck may be employed during extreme ventilation or in conditions of respiratory distress.

FIGURE 1-2. SCHEMATIC DIAGRAM OF THE AIRWAY



Schematic diagram of the airway. Progressive subdivision of the tracheo-bronchial tree illustrating both conducting airways and respiratory unit. From E.P. Horvath Jr., S.M. Brooks, and J.L. Hankinson [1981]. Manual of Spirometry in Occupational Medicine, U.S. Department of Health and Human Services, p. 5. (6).

FIGURE 1-3. A CLOSE-UP VIEW OF ALVEOLI AND CAPILLARIES



From E.P. Horvath Jr., S.M. Brooks, and J.L. Hankinson [1981]. Manual of Spirometry in Occupational Medicine, U.S. Department of Health and Human Services, p. 9. (6)

Normal expiration is a passive process resulting from the natural recoil or elasticity of the expanded lung and chest wall. (However, when breathing is rapid, the internal intercostal muscles and the abdominal muscles contract to help force air out of the lungs more fully and quickly.) A lung can be viewed as the opposite of a sponge. When a sponge is squeezed and released, its elasticity causes it to rebound to its larger initial size. At the end of an inspiration, the elasticity of the lung causes it to return to its smaller inter-breath size. The ability of the lung to do this is called **elastic recoil**.

The degree of stiffness or **compliance** of the lung tissue affects the amount of pressure needed to increase or decrease the volume of the lung. Lung compliance can affect elastic recoil. With increasing stiffness, the lung becomes less able to return to its normal size during expiration. Lung diseases are discussed later in this unit.

The amount of airflow **resistance** can also affect lung volumes. Resistance is the degree of ease in which air can pass through the airways. It is determined by the number, length, and diameter of the airways. An individual with a high degree of resistance may not be able to exhale fully, thus some air becomes trapped in the lungs.

The total capacity of the lungs is sometimes useful for understanding pulmonary pathology. A reasonable estimate of total lung capacity can be obtained by combining several volume parameters. (See **Figure 1-4. Lung Volumes**.) The most common parameters are:

1. **Tidal Volume** (TV): during quiet, relaxed breathing, the volume of air that is inhaled or exhaled with each breath.

2. **Expiratory Reserve Volume** (ERV): the maximal amount of air forcefully exhaled after a normal inspiration and expiration. The amount of exhaled air will be more than was just inhaled.

3. **Inspiratory Reserve Volume** (IRV): the maximal amount of air forcefully inhaled after a normal inhalation.

4. **Residual Volume** (RV): the amount of air remaining in the lungs after the deepest exhalation possible.

5. **Vital Capacity** (VC): The maximum amount of air that can be exhaled after the fullest inhalation possible. Vital capacity is the sum of the tidal volume, the inspiratory reserve volume, and the expiratory reserve volume. (The amount of air that can be exhaled with a maximal effort after a maximal inhalation is called the **Forced Vital Capacity** (FVC). The FVC is the volume that is measured in spirometry and will be discussed in more detail in subsequent units.)

6. **Total Lung Capacity** (TLC): the sum of the vital capacity and the residual volume.

(The reader may find it helpful to refer to **Appendix A. Glossary of Terms Commonly Used in Spirometry** when reading this and subsequent units.)

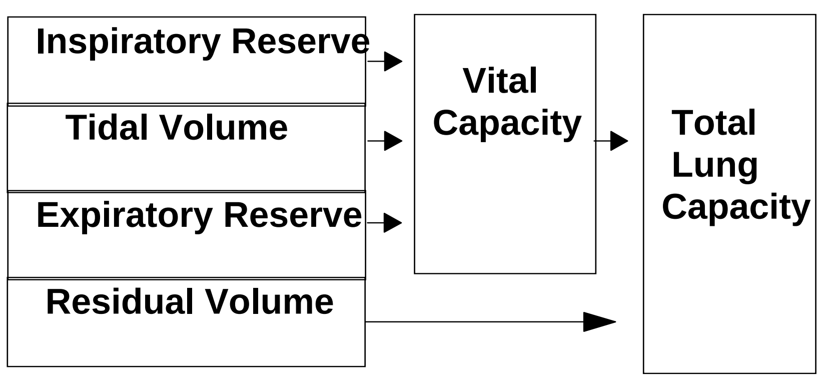


FIGURE 1-4. LUNG VOLUMES

C. Mechanisms for Protecting the Lungs against Airborne Hazards

Airborne contaminants can be in the form of gases (vapors), liquids (mists), or solids (smokes and dusts). (See **Appendix B. An Overview of Occupational Lung Hazards** for a discussion of common types of lung hazards seen in the occupational setting.) Toxic chemicals or irritating materials that are inhaled can damage the tracheo-bronchial tree or the lungs. These substances can cause harm in other parts of the body as well because the lungs provide an important route of exposure.

In order for a hazardous substance to affect the lungs, it must first pass through the bronchial tree and reach the alveoli. The body's defensive mechanisms prevent all but the smallest respirable particles from reaching the alveoli. The average person can see with the naked eye particles as small as 50 microns in diameter. (The symbol "μm" is the abbreviation for micron.) To put this in perspective, there are 25,400 microns in an inch or 10,000 microns in a centimeter. Smaller particles can sometimes be seen if a strong light is reflected from them (such as specks that can be seen in the air when sunlight streams through a window). Particles of respirable size are less than 10 microns and cannot be detected without a microscope.

The size, shape, and mass of particles affect where they are deposited in the respiratory system. Particles bigger than 5 microns usually do not remain airborne long enough to be inhaled or they are trapped by the nose. Heavier particles also settle out quickly and are easily removed if they are inhaled. Particles of intermediate size (1-5 microns) are more likely to deposit in the trachea and bronchi. Small particles (0.01-1 micron) are more likely to reach the bronchioles, alveolar ducts, and alveoli. Fibrous or irregularly shaped particles tend to become caught at bronchiole branching points. However, some fibers and small particles travel readily to the alveoli because of their aerodynamic properties.

The lungs have several mechanisms to protect themselves from contamination by particles and infectious agents. The fine hairs in the nose provide the front-line barrier by filtering out large dust particles and other materials. However, when individuals exercise or work hard, they need to breathe through their mouths to get enough air, and the nasal filtering system is bypassed.

The cough reflex clears foreign material from the trachea and main bronchi. Whenever irritating materials touch the walls of these airways, the chest and lungs quickly contract. As a result, air is rapidly forced out of the lungs, which usually expels the irritant.

The trachea, bronchi, and larger bronchioles are lined with fine, hair-like ciliary cells. These are covered with a thin layer of mucous that catches foreign material. The cilia rhythmically beat and move the mucous-trapped material up to the throat where it can be swallowed or spit out, and thus eliminated from the body. This process is called the mucociliary escalator (see **Figure 1-5. Mucociliary Escalator**).

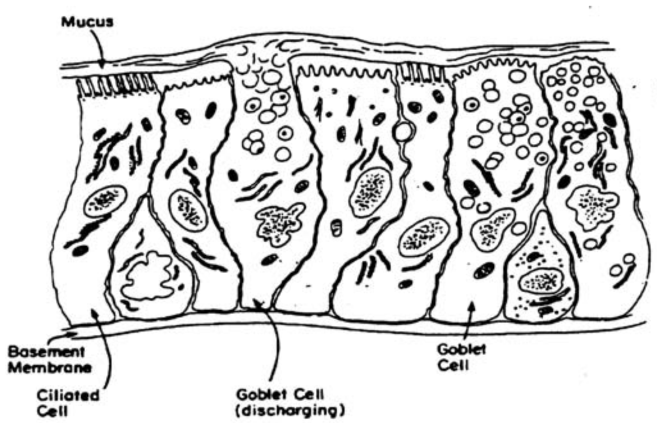


FIGURE 1-5. MUCOCILIARY ESCALATOR

The tracheal lining showing ciliated and goblet cells and the mucous layer. This is called the "mucociliary escalator."

From E.P. Horvath Jr., S.M. Brooks, and J.L. Hankinson [1981]. Manual of Spirometry in Occupational Medicine, U.S. Department of Health and Human Services, Cincinnati, p. 9. (6)

Alveolar macrophages are specialized cells that mobilize to destroy bacteria and viruses. In healthy lungs, the production of macrophages and mucous increase as needed to remove foreign matter and then return to normal levels.

Coughing usually removes irritating particles instantly and the mucociliary escalator may take only a few hours to expel foreign materials. However, the innermost areas of the lungs can take considerably longer to clear out foreign matter (7). Lungs that receive prolonged or repeated exposure to air contaminants eventually cannot keep up with the rate of deposition and/or the constant irritation. As a result, the contaminants accumulate, contributing to the development of occupational lung diseases.

D. Smoking and Occupational Lung Disease

Smoking contributes to lung disease in several ways. It impairs the lungs' natural defense mechanisms by irritating the airways and inhibiting the work of macrophages and the mucociliary escalator. In itself, it is a leading cause of serious lung and heart disease and certain types of cancer. It also has a synergistic effect with other pulmonary carcinogens, such as asbestos, chromium and uranium compounds, and arsenic. Synergistic means that the combined effect of two or more substances is greater than the effects of each added together. Smoking increases the risk of lung cancer by 15%, chronic asbestos exposure by 4%, but together they produce a 60% increase in risk, not a 19% increase (8). As a result, smokers who receive prolonged occupational exposures to other airborne contaminants develop heart and lung disease and cancer more readily than do nonsmokers with comparable exposures, and these diseases progress more rapidly because of the extra burden on the lungs created by smoking.

E. Occupational Lung Diseases

Spirometry is used to detect lung abnormalities that show obstructive or restrictive patterns, or a combination of the two. (See **Appendix C. Overview of Occupational Lung Disease** for descriptions of some of the better known occupational lung diseases. Also see **Appendix D. Respiratory Surveillance Programs** for information on the role of spirometry in the medical surveillance of occupational lung disease.) Obstructive diseases or abnormalities interfere with the flow of air into and out of the lungs. The underlying disease process frequently alters the diameter or integrity of the airways, causing increased airflow resistance from bronchospasm, mucosal edema, and increased production of secretions. Emphysema is one form of obstructive disease. When individuals with emphysema exhale (especially if they exhale forcefully) the airways narrow further or collapse. Asthma and chronic bronchitis are other common obstructive diseases. Restrictive diseases, such as asbestosis and silicosis, are caused by fibrotic tissue changes that reduce the ability of the lungs to expand (i.e., they have low compliance) but do not necessarily affect air flow. Disorders that affect the neuromuscular functioning of the chest wall may also produce a restrictive pattern. Other lung diseases, such as pneumonia, may show both obstructive and restrictive patterns.