Pulmonary volumes and capacities

Pulmonary ventilation can be studied by recording the volume movement of air into and out of the lungs, a method called **spirometry**. **Figure 1** shows a spirogram indicating changes in lung volume under different conditions of breathing. For ease in describing the events of pulmonary ventilation, the air in the lungs has been subdivided in this diagram into four volumes and four capacities, which are the average for a **young adult man**. **Table 1** summarizes the average pulmonary volumes and capacities.

Pulmonary volumes

To the left in **figure 1** are listed four pulmonary lung volumes that, when added together, equal the maximum volume to which the lungs can be expanded. The significance of each of these volumes is the following:

1. The **tidal volume** is the volume of air inspired or expired with each normal breath, it amounts to about 500 milliliters in the average adult male.
2. The **inspiratory reserve volume** is the extra volume of air that can be inspired over and above the normal tidal volume when the person inspires with full force; it is usually equal to about 3000 milliliters.
3. The **expiratory reserve volume** is the maximum extra volume of air that can be expired by forceful expiration after the end of a normal tidal expiration; this volume normally amounts to about 1100 milliliters.
4. The **residual volume** is the volume of air remaining in the lungs after the most forceful expiration; this volume averages about 1200 milliliters.

Pulmonary capacities

In describing events in the pulmonary cycle, it is some times desirable to consider two or more of the volumes together. Such combinations are called **pulmonary capacities**. To the right in figure 1 are listed the important pulmonary capacities, which can be described as follows:

1. The **inspiratory capacity** equals the tidal volume plus the inspiratory reserve volume. This capacity is the amount of air (about 3500 milliliters) a person can breathe in, beginning at the normal expiratory level and distending the lungs to the maximum amount.
2. The **functional residual capacity** equals the expiratory reserve volume plus the residual volume. This capacity is the amount of air that remains in the lungs at the end of normal expiration (about 2300 milliliters).
3. The **vital capacity** equals the inspiratory reserve volume plus the tidal volume plus the expiratory reserve volume. This capacity is the maximum amount of air a person can expel from the lungs after first filling the lungs to their maximum extent and then expiring to the maximum extent (about 4600 milliliters).
4. The **total lung capacity** is the maximum volume to which the lungs can be expanded with the greatest possible effort (about 5800 milliliters), it is equal to the vital capacity plus the residual volume.

Table 1: Pulmonary volumes and capacities

Pulmonary Volumes and Capacities	Normal Values (ml)
Volumes	
Tidal volume	500
Inspiratory reserve volume	3000
Expiratory volume	1100
Residual volume	1200
Capacities	
Inspiratory capacity	3500
Functional residual capacity	2300
Vital capacity	4600
Total lung capacity	5800

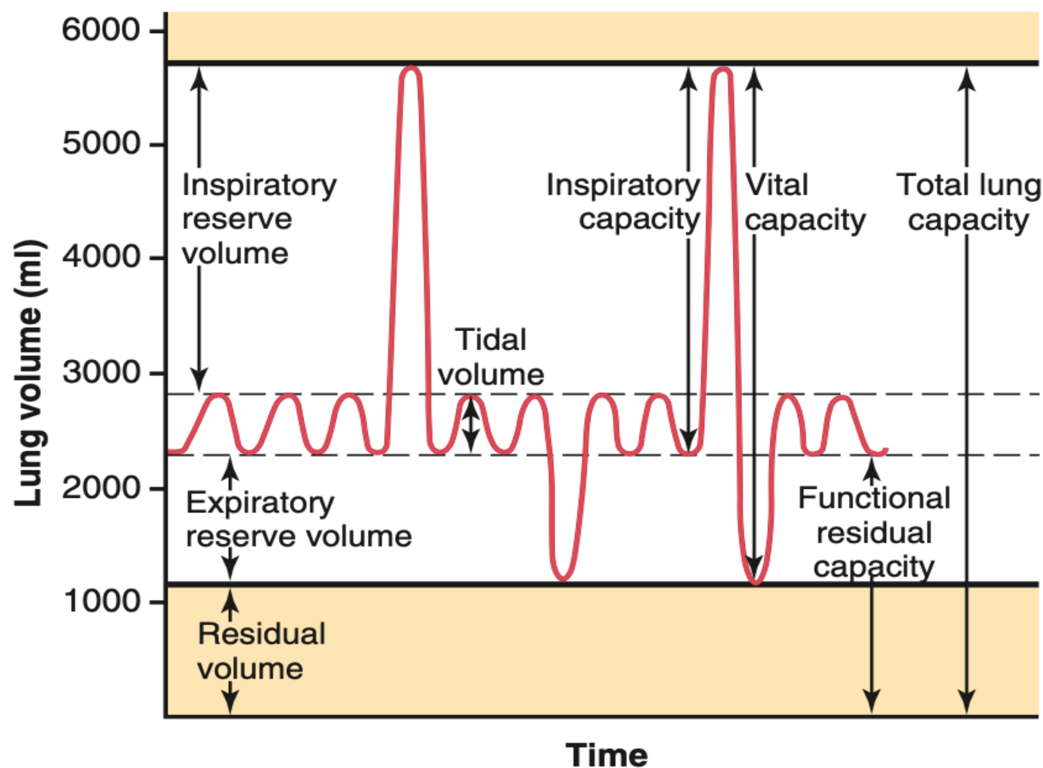

Figure 1: A diagram showing respiratory excursions during normal breathing and during maximal inspiration and maximal expiration.

All pulmonary volumes and capacities are usually about 20 to 25 percent less in women than in men, and they are greater in large and athletic people than in small and asthenic people.

Diffusion of gases through the respiratory membrane

Respiratory unit (also called "respiratory lobule"), which is composed of a **respiratory bronchiole**, **alveolar ducts**, and **alveoli**. There are about 300 million alveoli in the two lungs, and each alveolus has an average diameter of about 0.2 millimeter. The alveolar walls are extremely thin, and between the alveoli is an almost solid network of interconnecting capillaries.

Indeed, because of the extensiveness of the capillary plexus, the flow of blood in the alveolar wall has been described as a "sheet" of flowing blood. Thus, it is obvious that the alveolar gases are in very close proximity to the blood of the pulmonary capillaries. Further, gas exchange between the alveolar air and the pulmonary blood occurs through the membranes of all the terminal portions of the lungs, not merely in the alveoli. All these membranes are collectively known as the **respiratory membrane**, also called the **pulmonary membrane**.

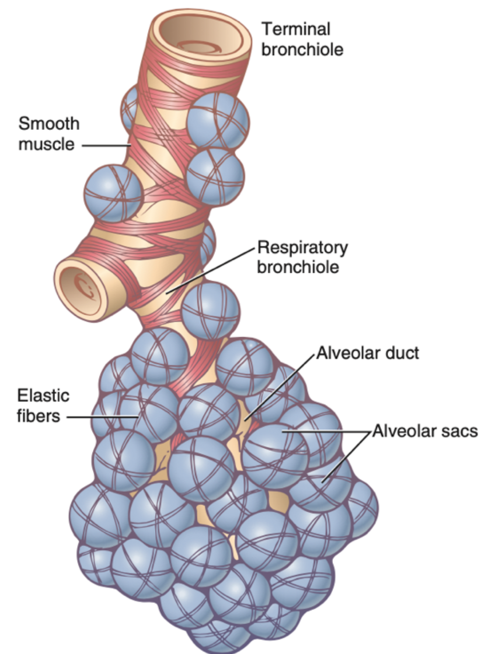

Figure 2: Respiratory unit

Figure 3 shows the ultra-structure of the respiratory membrane drawn in cross section on the left and a red blood cell on the right. It also shows the diffusion of O_2 from the alveolus into the red blood cell and diffusion of CO_2 in the opposite direction. Note the following different layers of the respiratory membrane:

1. A layer of fluid containing surfactant that lines the alveolus and reduces the surface tension of the alveolar fluid.
2. The alveolar epithelium, which is composed of thin epithelial cells.
3. An epithelial basement membrane.
4. A thin interstitial space between the alveolar epithelium and the capillary membrane.
5. A capillary basement membrane that in many places fuses with the alveolar epithelial basement membrane.
6. The capillary endothelial membrane.

Despite the large number of layers, the overall thickness of the respiratory membrane in some areas is as little as 0.2 micrometer and averages about 0.6 micrometer, except where there are cell nuclei. From histological studies, it has been estimated that the total surface area of the respiratory membrane is about 70 square meters in the healthy adult human male, which is equivalent to the floor area of a 25 × 30 foot room. The total quantity of blood in the capillaries of the lungs at any given instant is 60 to 140 milliliters. Now imagine this small amount of blood spread over the entire surface of a 25 × 30 foot floor, and it is easy to understand the rapidity of the respiratory exchange of O_2 and CO_2.

The average diameter of the pulmonary capillaries is only about 5 micrometers, which means that red blood cells must squeeze through them. The red blood cell membrane usually touches the capillary wall, so O_2 and CO_2 need not pass through significant amounts of plasma as they diffuse between the alveolus and the red blood cell. This, too, increases the rapidity of diffusion.

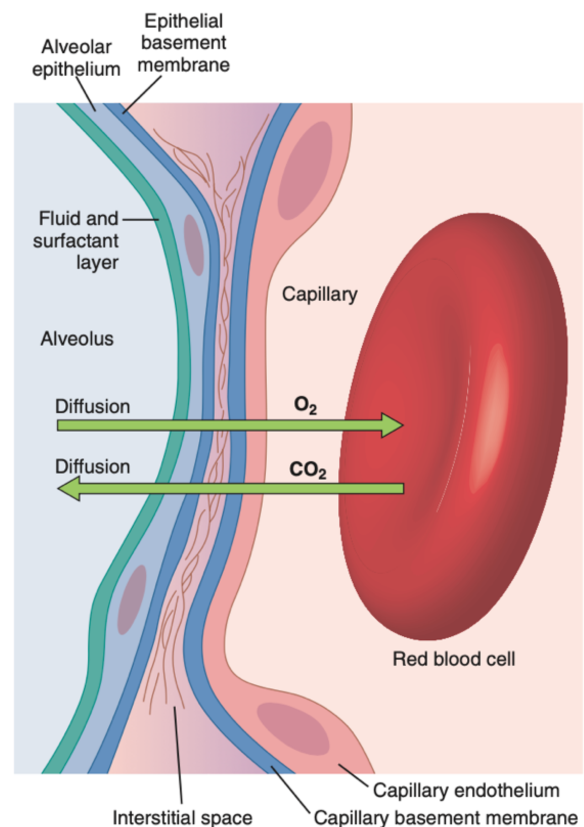

Figure 3: Ultrastructure of the alveolar respiratory membrane, in cross section