# Chapter 9
# Flow in the Lungs

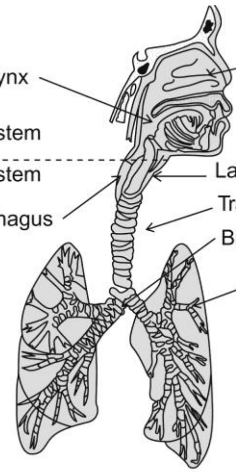


**Figure 9.1** Anatomical arrangement of the components of the respiratory system. Air enters from either the nose (nasal cavity) or the mouth and passes into the pharynx. From here, air passes through the larynx, the trachea, and the primary bronchi. The bronchioles continually divide until the air reaches the alveoli where gas is exchanged with the cardiovascular system. Only the conducting portion of the respiratory system is shown in this figure.

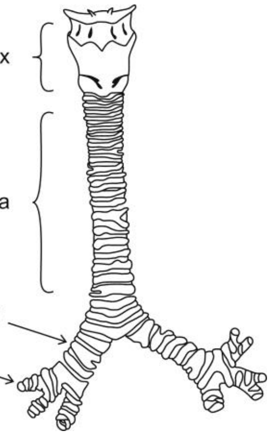


**Figure 9.2** Schematic of the lower respiratory system, which is composed of the larynx, the trachea, and the bronchi. The trachea and the bronchi are surrounded by cartilage to maintain the rigid shape of this portion of the respiratory system.

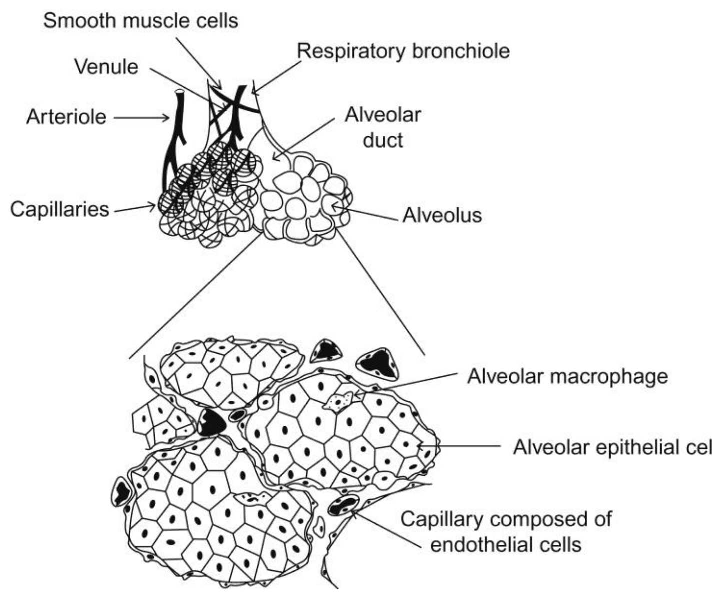


**Figure 9.3** The anatomical structure of a single alveolar lobule. Each lobule is surrounded by a capillary network to efficiently exchange gas with the alveolar space. Bronchioles are wrapped with smooth muscle cells to change the diameter of the bronchiole and increase or decrease the resistance of air flow into the alveolar sac. This figure also shows an expanded section of an alveolar sac, which is composed of epithelial cells and the surrounding capillaries. *Adapted from Martini and Nath (2009)*.

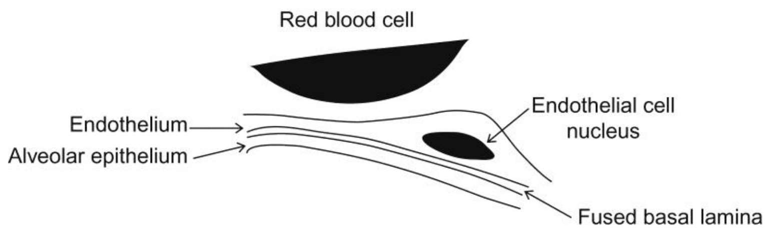


**Figure 9.4** The respiratory membrane, which is composed of an alveolar epithelial cell, a capillary endothelial cell, and their fused basal lamina layer. In general, a red blood cell would be within one cell diameter of the endothelial cell. As discussed in the text, this boundary can be modeled as a single permeable membrane or a composite permeable membrane (with different diffusion permeabilities). *Adapted from Guyton and Hall (2000)*.

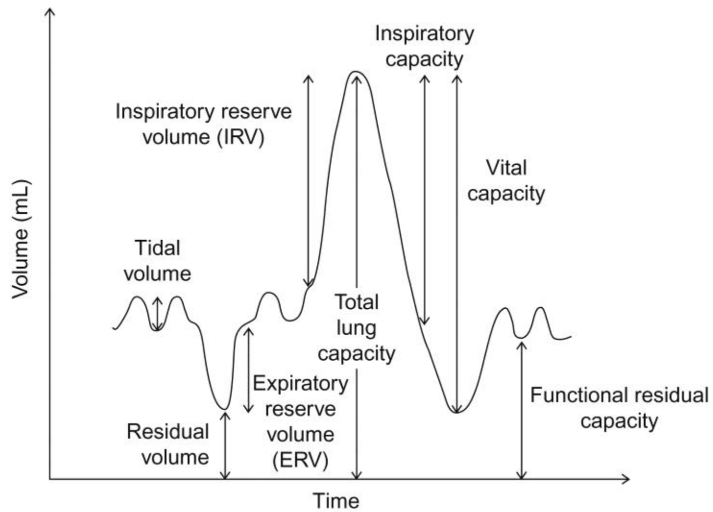


**Figure 9.5** The volume of the lungs under normal breathing and various other respiratory movements. Under normal conditions, the tidal volume will be approximately 500 mL for each breath and there is an inspiratory reserve volume of approximately 3300 mL and an expiratory reserve volume of approximately 1000 mL. The total lung volume is approximately 6000 mL.

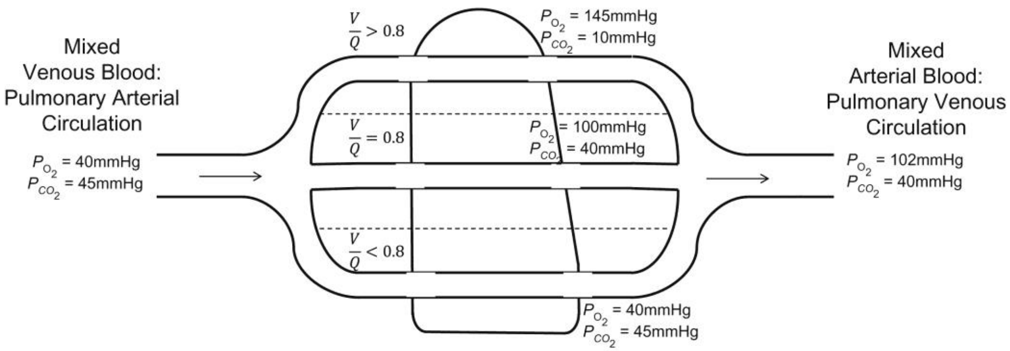


**Figure 9.6** Ventilation perfusion ratio for lungs in an elevated position. Under normal conditions the upper portion of the lungs has very low flow with a higher ventilation. This allows the blood from this zone to have an elevated oxygen and reduced carbon dioxide concentration as compared with mixed arterial blood. The middle zone has an oxygen and carbon dioxide concentration that is close to that of mixed arterial blood. Finally, the lowest zone has a reduced oxygen and an elevated carbon dioxide concentration as compared with mixed arterial blood, because this portion of the lungs is not ventilated well.

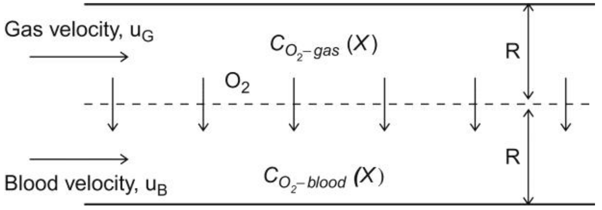


**Figure 9.7** Respiratory boundary modeled as a semipermeable membrane. Using this type of model, the diffusion of respiratory gases across the respiratory boundary can be calculated if we assume that the total concentration of the gas remains constant along the channel.

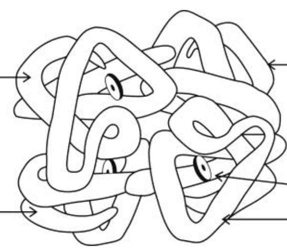


**Figure 9.8** The protein structure of hemoglobin, which consists of four globular protein subunits. Each subunit contains one heme molecule, which is a non-protein compound that surrounds an iron core. It is this iron molecule that facilitates the transport of oxygen and carbon dioxide. Each red blood cell contains close to 300 million hemoglobin molecules. *Adapted from Martini and Nath (2009)*.

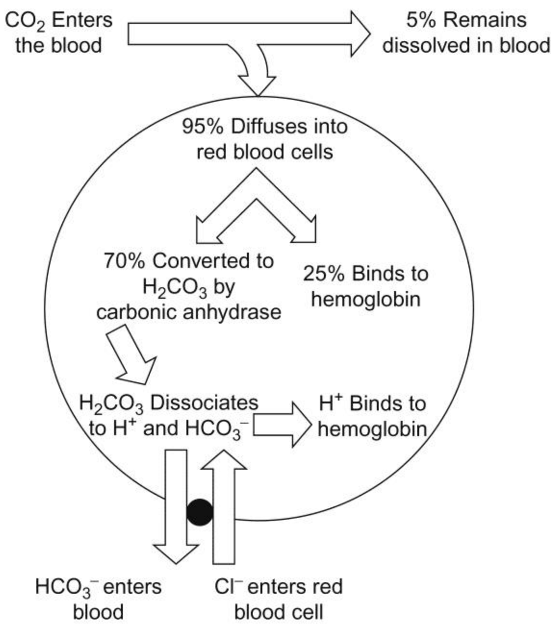


**Figure 9.9** Pathways for carbon dioxide transportation in blood at a carbon dioxide partial pressure of 45 mmHg. The majority of carbon dioxide is converted to hydrogen and bicarbonate ions. About 25% of the carbon dioxide binds directly to free amino groups in the hemoglobin protein. The remaining carbon dioxide is transported directly within the blood.

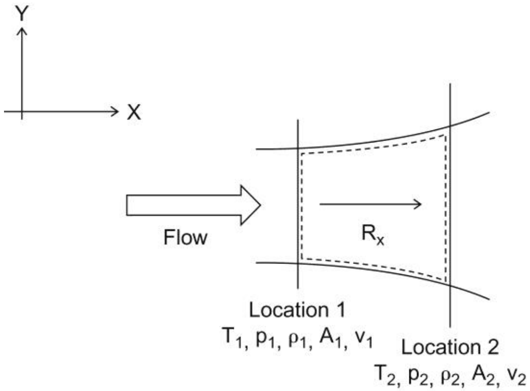


**Figure 9.10** General isentropic flow in an expanding channel. In general, we would be interested in the temperature, pressure, density, and velocity of the fluid for a given change in area. The fluid mechanics governing equations for compressible flows can be found in the following discussion.