How Does Oxygen Get to Muscles?

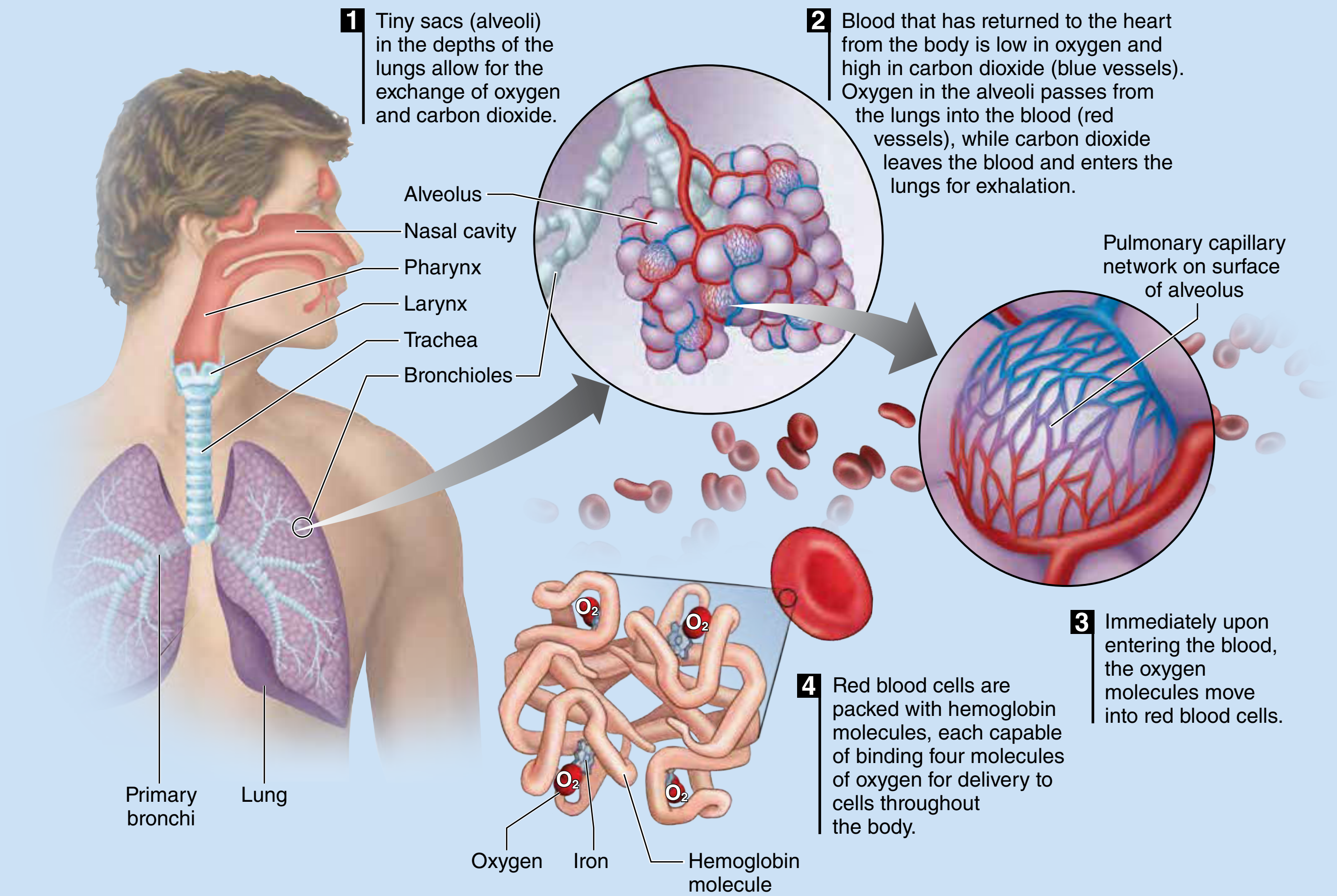
The human body is obviously well equipped to extract oxygen from inhaled air and deliver that oxygen to all cells in the body, including muscles. That process is actually very simple in concept, even though it's quite complicated in detail.

Lungs allow oxygen from inhaled air to pass across the very thin membranes in the depths of the lungs and enter the bloodstream. At the same time, carbon dioxide that was produced by muscles and other cells leaves the blood, passing across the lung membranes to be exhaled from the body. This exchange is illustrated in figure 3.1.

Some of the oxygen in inhaled air passes across the lungs into the blood. At the same time, carbon dioxide is released from the blood and enters the lungs to be exhaled. The movement of those two gases—O_2 and CO_2—depends on their concentrations and their diffusion coefficients. The diffusion coefficient is a measure of how quickly a substance tends to move across a membrane like the lining of the lung alveoli. For example, even though CO_2 is in low concentration in the blood flowing through the lungs, it moves easily from the blood into the lungs because CO_2 has a high diffusion coefficient, 20 times greater than O_2 has.

Oxygen is so critical to survival that, even at the cellular level, all nucleated cells in the body can sense oxygen.

FIGURE 3.1 The exchange of oxygen and carbon dioxide at the lungs. Oxygen binds to hemoglobin in the blood. Iron is an important part of each hemoglobin molecule.



When oxygenated blood reaches muscle cells, the bond between oxygen and hemoglobin molecules loosens. When the red blood cells pass single file through the tiny capillaries that surround muscle cells (figure 3.2), oxygen molecules are released from hemoglobin and diffuse into the muscle cells. The carbon dioxide produced by the muscle cells diffuses into the bloodstream not as CO_2 but as bicarbonate ion (HCO_3^-) that is converted back into CO_2 in the lungs, where it is exhaled.

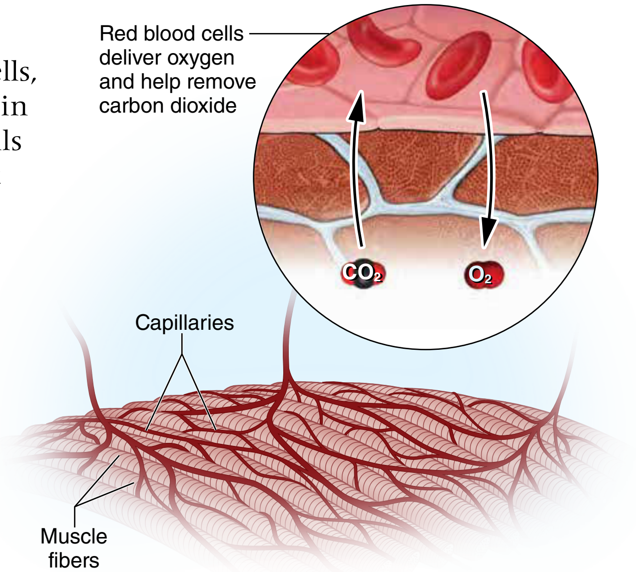


FIGURE 3.2 Muscle cells are supplied by tiny capillaries that deliver oxygen and nutrients and remove waste products such as carbon dioxide and lactic acid.

Once inside muscle cells, the oxygen can either bind to *myoglobin* (a protein like hemoglobin that enables muscle cells to store a small amount of oxygen) or enter the mitochondria to be used in the electron transport chain to accept the H^+ ions produced by the oxidation of carbohydrate and fat. Before binding with oxygen to form H_2O, the H^+ ions are used in the electron transport chain to produce ATP. The complete oxidation of carbohydrate and fat produces ATP, H_2O, CO_2, and heat.

The process by which carbohydrate and fat are oxidized to produce ATP is referred to as *internal respiration* because it occurs inside cells. The delivery of oxygen from the lungs to the cells is called *external respiration*.

The Role of Iron in Oxygen Transport

Even though the human body contains only 3 to 4 grams of iron, that small amount plays a variety of important roles. The iron in each hemoglobin molecule binds oxygen for transport; in fact, the color of blood is due in part to those iron molecules. Myoglobin in muscle cells also contains iron molecules; myoglobin serves as a way station for oxygen molecules on their short journey from the red blood cells into the mitochondria. And iron molecules are important for the function of many enzymes.

Iron is a mineral needed in small amounts on a daily basis (8 mg per day). Red meat, beans, fish, and leafy vegetables are good sources of iron. Some female athletes are prone to iron deficiency because of iron loss during menstruation combined with low iron intake in their diets. If iron deficiency becomes severe, anemia (abnormally low hemoglobin level) can result. Iron deficiency and anemia are far more common in females than in males.

Measuring the iron content in blood is not useful in determining a person's iron status, but other measures such as plasma ferritin (the storage form of iron) are used to determine whether someone is iron deficient. If iron stores become too low, the bone marrow has a difficult time maintaining normal hemoglobin production, and iron-deficiency anemia can result. It is possible for athletes to have iron deficiency without anemia; some estimates indicate that 20% to 25% of female athletes are iron deficient (below-normal plasma ferritin levels). Whether or not performance is adversely affected by iron deficiency is a matter of debate, but there is no doubt that iron deficiency is abnormal and should be addressed through changes in diet and perhaps daily intake of an iron supplement.

Reference: Rowland, T. (2012). Iron deficiency in athletes. *American Journal of Lifestyle Medicine, 6*(4):319-327.