Medical Physics

The Physics of the Lungs and Breathing

Lecture Five

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Introduction:

The human **"machine"** really consists of billions of very small "engines" the living cells of the body. Each of these miniature engines must be provided with fuel O_2.

The blood and its vessels **(cardiovascular system)** serve as the transport for these engines.

The lungs **(pulmonary system)** serve as the supplier of O_2.

The blood takes the O_2 to the tissues and removes the CO_2 from the tissues; it must come in close contact with the air in the lungs in order to exchange its load of CO_2 for a fresh load of O_2.

The function of the Lungs

1. Exchanging of O_2 and CO_2 between blood and air.

2. Keeping the PH (acidity) of the blood constant.

$$CO_2 + H_2O \rightarrow H_2CO_3$$

3. Heat exchange between the body and atmosphere.

4. Keeping the fluid of the body balance by warming and moisturizing the air we breathe.

5. Voice production.

Breathing Rate

- We breathe about 6 liters of air per minute.
- Men breathe about 12 times per minute at rest.

- Women breathe about 20 times per minute at rest.
- Infants breathe about 60 times per minute at rest.

The air we inspired is about 80% N_2 and 20% O_2.

Expired air is about 80% N_2, 16% O_2 and 4% CO_2.

We breathe about 10 Kg of air each day.

The lungs absorbs 400 liters of O_2 and release a slightly smaller amount of CO_2.

Each time we breathe, about 10^{22} molecules of air enter our lungs. Each liters of air contain about $6x10^{23}$ molecules (Avogadro's number).

The Airways

The principal air passage into the lungs are shown in figure (1). Air normally enters the body through the nose where it is warmed, filtered and moisturized.

The air then passes through windpipe (trachea). The trachea divides into two (bifurcates) to furnish air to each lung through the bronchi. Each bronchus divides and re divides about 15 more times, the resulting terminal bronchioles supply air to millions of small sacs called alveoli.

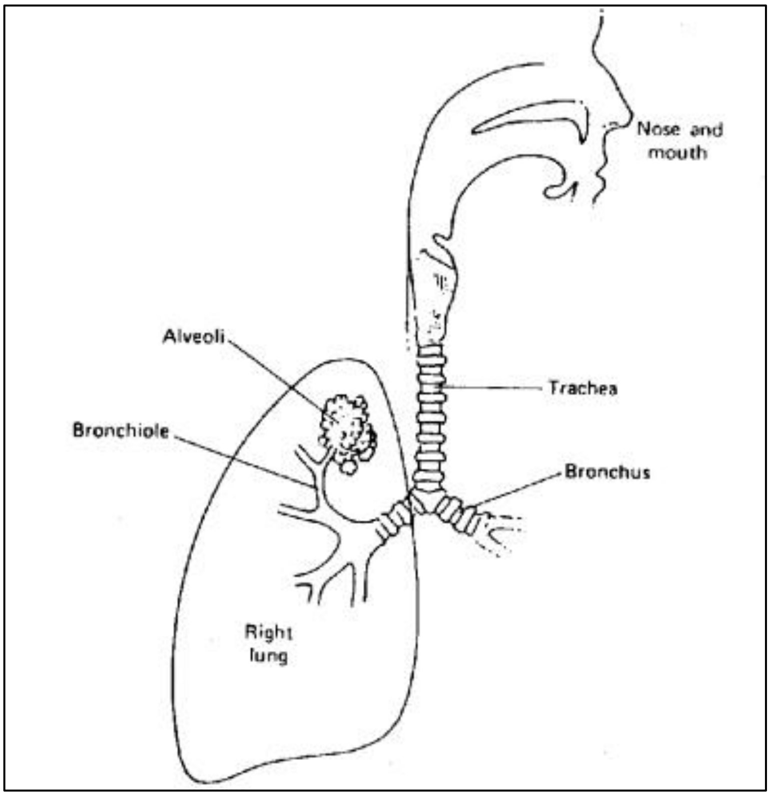

Figure 1: A schematic diagram showing the principal air passages into the lungs.

The alveoli is small interconnected bubbles are about 0.2mm in diameter and have walls only 0.4μm thick (figure 2).

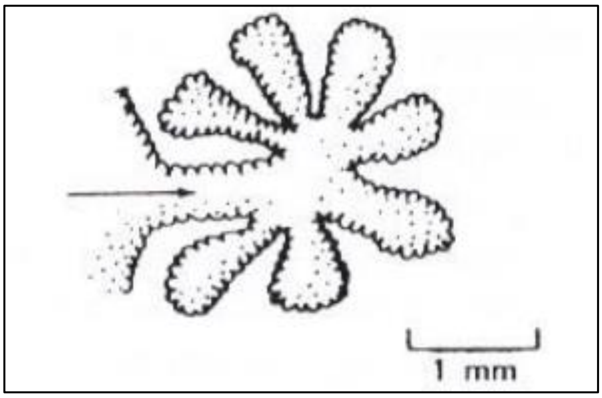

Figure 2: The structure of the alveoli.

How Blood and Lungs Interact

The primary purpose of breathing are to bring a fresh supply of O_2 to the blood in the lungs and to dispose of the CO_2.

The physical law of diffusion controls the transfer of O2 and CO2 into and out of the blood.

All molecules are continually in motion. In gases and liquids, and to a certain extent even in solids, the molecules do not remain in one direction.

Molecules of a particular type diffuse from region of higher concentration to a region of lower concentration until the concentration is uniform.

In the O_2 and CO_2 exchange in the tissues, we are concerned only with diffusion in liquids. The molecules in a gas at room temperature move at about the speed of sound. Each molecule collides about 10^{10} times each second with neighbouring molecules.

The distance D of the molecule will travel from its origin after N collisions is

$$\mathbf{D = \lambda \sqrt{N}}$$

Where

N number of collisions

λ is the mean free path or the average distance between collisions.

in air → $\lambda = 10^{-7}$ m

in tissue → $\lambda = 10^{-11}$ m

Example: What is the typical value of D in air and in tissue for an O_2 molecule after 1sec if N= 10^{10} in air and in tissue N = 10^{12}?

In air D = 10^{-7} $(10^{10})^{½}$ =10^{-2} m

In tissue D = 10^{-11} $(10^{12})^{½}$ = 10^{-5} m

Diffusion depends on the speed of the molecules, the speed of molecules increases with temperature.

In the lungs, the distance to be travelled in the air is usually a small fraction of a millimeter, and diffusion takes place in a fraction of a second.

The diffusion of O_2 and CO_2 in tissue is about 10,000 times slower than it is in air, but the tissue thickness of the molecules that must diffuse through in the lungs is very small 0.4μm.

To understand the behavior of gases in the lungs it is necessary to know Dalton's law of partial pressures. Dalton's law state that if you have a mixture of several gases, each gas makes its own contribution to the total pressure as though it were all alone.