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Medical Physics

Physics of the Lungs and Breathing

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The Physics of Lungs and Breathing

Function of Lungs & Breathing:

1. Exchange of $\mathbf{O_2}$ & $\mathbf{CO_2}$ between the blood and air.
2. Keeping PH (acidity) of the blood constant.
   "When we do work PH increase "$\mathbf{CO_2 + H_2O \rightarrow H_2CO_3}$"
3. Heat exchange between the body and atmosphere.
4. Fluid balance of the body by warming and moistening the air we breathe.
5. Voice production.
6. Removing the dust particles stuck to the moist lining of various air ways.

Breathing Rate:

1. We breathe ≈ 6 liters of air per min.
2. Men breathe ≈12 times / min at rest
3. Women breathe ≈ 20 times / min at rest.
4. Infants breath ≈ 60 times / min at rest.

* The air we inspired is ≈ 80 % N_2, 20 % O_2.

**Expired air is ≈ 80 % N_2, 16 % O_2 & 9 % CO_2.

The Airways

The principal air passage into the lungs are shown in Fig (1). Air normally enters the body through the nose where it is warmed, filtered and moisturized .The air then passes through trachea .The trachea divides into two to furnish air to each lung through the bronchi. Each bronchus divides and re divides about 15 times, the resulting terminal bronchioles supply air to millions of small sacs called alveoli.

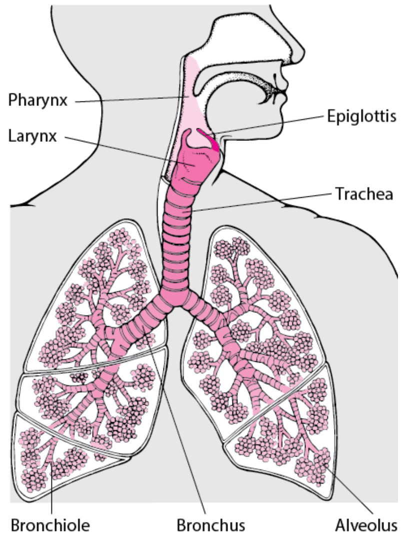


Figure 1: Showing the principal air passages into the Lungs.

Nose ⟶ Trachea ⟶ Bronchi ⟶ Bronchioles ⟶ Supply air to small Sacs called alveoli.

1. The nose: Air is warmed, filtered and moistened by the moist surface and hairs, which trap particles and dirt.
2. The trachea: A wind pipe that the air passes through goes to a lung.
3. The bronchi: Two divisions from the trachea .Each bronchus go to a lung.
4. Bronchioles: Each bronchus divides and divides 15 times into smaller branches call bronchioles.
5. Alveoli: Air sacs 30 million at birth, 300 million at age 8 years and more, beyond this age the number of stays relatively constant but the alveoli increase in diameter. Alveoli which are like small interconnected bubbles are about 0.2mm in diameter and half a wall's only 0.4 micrometer thick in, the expand and control during breathing.

There are two processes involved O_2 and Co_2 exchange in the lung:

1. Perfusion (P): getting the blood to the pulmonary capillaries.
2. Ventilation (V): getting the air to the alveolar surface.

There are three P- V. areas in the lung:

1. Areas with good. P. good V. which accounts over 90% of the total volume of normal lung.
2. Areas with poor P. good V. where a blood flow to part of a lung is blood by a clot.
3. Areas with good P. poor V. where air passages in the lungs are obstructed as in pneumonia.

The transfer of O2 and CO2 into and out of the blood is controlled by physical ***law of diffusion*. In lungs, diffusion occurs in both gas and liquids.

Diffusion in gases: 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 neighboring molecules. The distance **D** of molecule will travel from its origin after **N** collisions is

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

Where

N = no. of collisions.

D = diffusion distance.

λ = mean free path.

λ is defined as the average distance between collision. 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 1 sec if $N = 10^{10}$ in air and in tissue $N = 10^{12}$?

Solution:

$$\text{In air } D = 10^{-7}\,(10^{10})^{1/2} = 10^{-2}\text{ m}$$

$$\text{In tissue } D = 10^{-11}\,(10^{12})^{1/2} = 10^{-5}\text{ m}$$

Dalton's law of partial pressures

Dalton's law state that if you have a mixture of several gases, each gas make its own contribution to the total pressure as though it were all alone.
The pressure exerted by any one of the gases is known as the partial pressure of that gas, and the total pressure of these gases is the sum of the partial pressures of the mixture gases.

$$\mathbf{p_{total} = p_{t1} + p_{t2} + p_{t3}} \text{ -----}$$

Where p is a partial pressure
Example: Air contained 80% N_2 , 20% O_2, At atmospheric pressure (760 mmHg)
Solution:

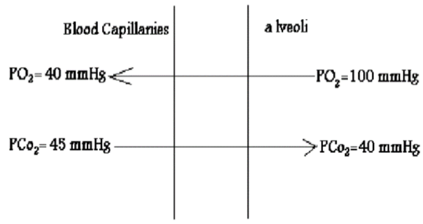
$$p_{O_2} = 20/100*760 = 152 \text{ mmHg}$$
$$p_{N_2} = 80/100*760 = 608 \text{ mmHg}$$

Partial Pressures of O2 and CO2

The behavior of the gases (Air exchange by diffusion) obeys to the Dalton's Law of partial pressures (The total pressure of different gases is the sum of the pressures of each would exert when it alone occupied the contained).

Partial Pressure = % (gas)* (atmospheric – partial pressure of water vaporH_2O).

In the lung → at $37C^{\circ}$& 100 % relative humidity, the partial pressure of water vapor = 47mmHg,
Example: The alveolar air contain 14% O_2 and 5.6% CO_2 . Find the partial pressures of $O_2$and CO_2
Solution:
Atmospheric pressure = 760mm Hg
The alveolar airs contain → 14%O_2 & 5.6% CO_2.
p_{O_2}= 14/100* (760mm Hg – 47 mm Hg) =100 mm Hg.
p_{CO_2}= 5.6/100* (760mm Hg – 47 mm Hg) = 40mm Hg.

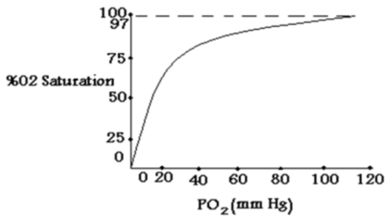


Henry Law

The state the solubility of gases in liquids "The volume of gas will dissolve directly in a liquid proportional to the partial pressure of the gas"
PO_2→ 200 mmHg. O_2 dissolved in the blood will double the amount of gas dissolved in the blood varies greatly from one gas to another.

Combination of O2 with Hb (Hemoglobin)

- ✓ Because of the low solubility of O_2 in the blood most of the O_2 combine with Hb in the blood red cells to be carried to the body cells.
- ✓ The Hb leaving the lungs ≈ 97% saturated with O_2 at p_{O_2}=100 mmHg.
- ✓ O_2 Dissociate from Hb and diffuse into the cells because of their low p_{O_2} environment.



CO2 Transporting

- ✓ Most of CO_2 remains in the blood after it have left the lungs (PCO_2 =40mm Hg). The CO_2 levels in the blood are maintained fairly constant by the breathing rate.

*The ratio of CO_2 output to O_2 in take is called Respiratory exchange ratio (Respiratory quotient) R<1

- ✓ At each normal breath ≈ 500cm^3 of fresh air (PO2 150mm Hg) mixed with ≈ 2000cm^3 of stale air in the lung to result in alveolar air with PO2 ≈ 100mm Hg.

CO Poisoning (Carbon monoxide)

1. CO molecules attach with Hb nearly 250 times more tightly than O_2.
2. Do not easily dissociate in the tissue.
3. Occupy places in Hb normally used to transport O_2.
4. CO inhibits the release of O_2 from Hb

So even a small amount CO can seriously reduce the O_2 to the tissue.

Measurement of lung volumes

Spirometer simple instrument, is used to measure air flow into and out of the lungs and record it on a graph of volume versus time.

The lung has various volumes and capacities. The volume of the lung versus time (i.e. the air flow) can be measured by the spirometer which record it on a graph. These volumes and capacities can be summarized as follows which is shown in Fig. (2)

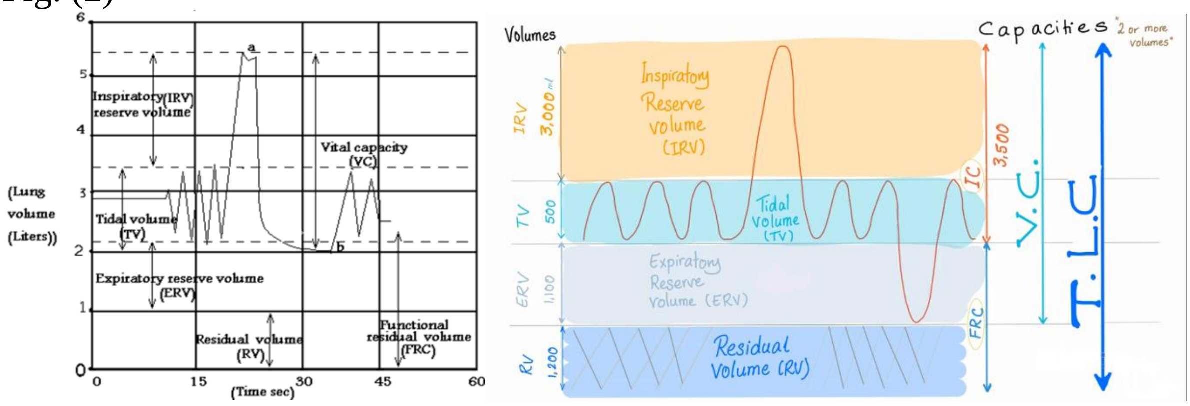


Figure 2: Shows the various volume and capacities of the lungs.

1. ***Tidal volume at rest (TV):***
   It is the volume of air inhaled with each breath during normal breathing at rest (~ 500 cm3). During heavy exercise the tidal volume is considerably large.
2. ***Inspiratory reserve volume (IRV):***
   It is the additional air taken at the end of inspiration, which is possible with some effort to further fill the lungs with air.
3. ***Expiratory reserve volume (ERV):***
   It is the additional expired air, which can be forced out of the lungs at the end of normal expiration.
4. ***Functional residual capacity (FRC):***
   It is the air remaining in the lungs after a normal respiration where the stale air mixes with the fresh air of the next breath.
5. ***Vital capacity (VC):***
   The volume of air exhaled when the breath is as deeply as possible and then exhaled as much as possible.
6. ***Residual volume (RV):***
   It is the amount of air stale in lungs after vital capacity, which is ~1lit for adult.

Dead Spaces:

There are spaces in respiratory system at which air does not provide O_2 to the body.

150 cm^3 + 350 cm^3 =500cm^3
A.D. spaces alveolar air

Anatomic dead spaces:

a) Fresh air does not go directly to alveoli .It goes first through the conducting airway .Because there is no significant exchange of O_2 & CO_2 between gas & blood in the conducting air way, the internal volume of airway is called anatomic dead space.
b) Physiological (alveolar) dead spaces: It is the unused alveolar volumes, in which alveolar capillaries are not perfuse with blood, and O2 is not absorbed in the alveoli.

Airway diseases test

*The maximum rate of expiration after a maximum inspiration is a useful test for obstructive airway diseases where the flow rate sometimes decreases with excessive expiratory effect. During the maximum expiration the out flow is rapid at first; the last 5% takes longer than the first 95%.

*A normal person can expire nearly 70% of his vital capacity in 0.5 sec., 85% at 1 sec., 94% in 2 sec., 97% in 3 sec