University AL-Qadisiyah/College of Medicine
Dept. of Physiology and Medical Physics, Medical Physics
Lecturer: Dr. Khalid Ibrahim

Chapter Seven: Physics of the lungs and breathing/PI

1. Function of the breathing system

1. Exchange of O_2 and CO_2
2. Keeping the pH (acidity) of the blood constant.
3. Play secondary roll in heat exchange and fluid balance.
4. Controlling flow of air for talking, coughing, ….etc.
5. Voice production.
6. Removing the dust particles stuck to the moist lining of various airways.

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The breathing:

The inhalation time is typically les than 20% of the breath cycle. The airway resistance produced by the vocal cord causes a sizable pressure increase in the trachea.
The voice typically has a power of less than 1 mW.
We breathe about 6 liters of air per min.

Breathing rate = Breathe / min.

At rest:
The breathing rate in: men =12 times / min.
women = 20 times / min.
Infants = 60 times / min.

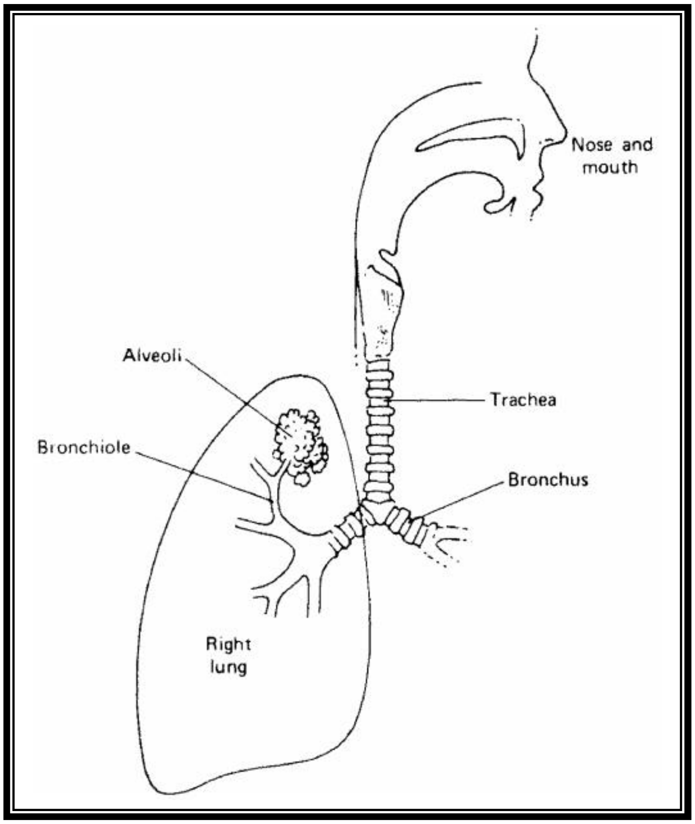
Inspired air is about: 80% N_2 and 20% O_2
Expired air is about: 80% N_2 and 16% O_2 and 4% CO_2

We breathe about 10 kg of air each day. Of this the lungs absorb about 0.5 kg of O_2 and release a slightly smaller amount of CO_2. We also saturate the air we breathe with water. When we breathe in dry air, our expired air carries a way ~ 0.5 kg of water each day.

- The surface area of the lungs = 80 m^2.
- Each time we breathe about 10^{22} molecules of air enter our lungs.

2. The airways:

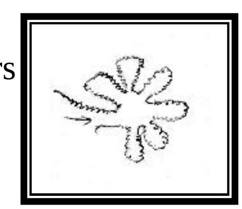
The air enters the nose where it's warmed, filtered, and moisturized. The air then pass through the trachea; that will be divides to enter each lung through the bronchi.
Each bronchus divides and re-divides about 15 more time; the resulting terminal bronchioles supply air to millions of small sacs called alveoli.



2.1 The alveoli:

Which are small interconnected bubbles, are about 0.2 mm in diameter, and have walls only 0.4 µm thick. They expand and contract during breathing. Each alveolus is surrounded by blood so that O_2 can diffuse from the alveolus into the red blood cells and CO_2 can diffuse from the blood into the air in the alveolus.

At birth the lungs have about 30 million alveoli; by age 8 yrs the number of alveoli has increased to about 300 million.



2.2 The function of the airways:

1. Transport system for the air.
2. Remove the dust particles that stick to the moist lining of the various air passages.

- The body has two mechanism for clearing the airways from foreign particles:

1. Large chunk are removed by coughing.
2. Small particles are carried upward toward the mouth by millions of small hairs.

3. Gas exchange in the lungs:

1. Blood is pumped from the heart to the lungs. The max. blood pressure in main pulmonary artery carrying blood to the lungs is only about 20 mmHg.
2. Blood volume: about 1 liter of the body's blood supply is in the lungs, but only about 70 ml of that blood is in the capillaries of the lungs getting O_2 at any one time (< 1 sec).
3. The lungs must be well designed for the gas exchange. How?

a- The alveoli of the lungs have extremely thin walls and are surrounded by the blood in the pulmonary capillary system.

b- The surface area between air and blood in the lungs is about 80 m^2 .

If the 70 ml of blood in the pulmonary capillaries were spread over a surface area of 80 m^2 the resulting layer of blood would be only about 1 µm thick, less than the thickness of a single RBC.

3.1 Ventilation and perfusion:

Two general processes are involved in gas exchange in the lungs:

1. Perfusion: getting the blood to the pulmonary capillary bed.
2. Ventilation: getting the air to the alveolar surfaces.

There are three types of ventilation –perfusion areas in the lungs:

1. Areas with good ventilation and good perfusion.
2. Areas with good ventilation and poor perfusion.
3. Areas with poor ventilation and good perfusion.

In a normal lung the first type accounts for over 90% of the total volume. The second occur if the blood flow to part of a lung is blocked by a clot that causes poor perfusion. In the third type the air passage in the lungs are obstructed.

3.2 Diffusion:

Diffusion: Molecules move from a region of higher concentration to low concentration until the concentration is uniform.
The transfer of O_2 and CO_2 into and out of the blood is controlled by diffusion.

Molecules movement:

In the lungs diffusion occurs in both gas and liquid (in tissues).
The molecules in gas at room temp. move at ~ speed of sound.
Each molecule collides ~ 10^{10} times each sec. with neighboring molecules.

The most probable distance D a molecules will travel from its origin after N collisions is $D = \lambda\sqrt{N}$.

Where
λ = is the mean free path
N = Number of collisions.
D = the distance which the molecules travel it after N collisions.

Note: In air λ is about 10^{-7} m.
In tissues λ is about 10^{-11} m.

Diffusion depends on:
1) The speed of the molecules.
2) Temp. (Increase with temp.).

- Since N is proportional to the diffusion time (Δt):
  $N \alpha \Delta t$

  We can write that $D \alpha \sqrt{\Delta t}$ or $\Delta t \alpha D^2$.

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

Daltons law: (for the partial pressure)

In a mixture of several gases, each gas makes it own contribution to the total pressure as though it were all alone.

* Example: Air contained 80% N_2 and 20% O_2
$PO_2 = (20/100) \times 760 = 150$ mmHg
$P N_2 = (80/100) \times 760 = 610$ mmHg

But, the partial pressure of water vapor in air depends in humidity.

Partial pressure = (gas)% x (Atomspheric pressure – Partial pressure of H_2O)

In lungs at 37Ċ and 100% relative humidity of partial pressure of water vapor is ~ 47 mmHg.

* Example: The alveolar air contains 14 % O_2 and 5-6% CO_2. Find the partial pressure of O_2 and CO_2?

PO_2 = (14/100) x (760- 47) = 100 mmHg
PCO_2 = (5- 6/100) x (760 - 47) = 40 mmHg

3.4 Henry`s law:

[The amount of gas dissolved in a liquid is proportional to it‘s partial pressure]

- The amount of gas dissolved in blood varies greatly from one gas to another.
- O_2 is not very soluble in blood or water [1 liter of blood plasma at a PO_2 = 100 mmHg will hold ~ 2.5 cm^3 of O_2 at normal temperature and pressure (NTP)].
- CO_2 is good soluble in blood or water [1 liter of blood plasma at PCO_2 = 40 mmHg will hold ~ 25 cm^3 of CO_2 in solution].
- The different solubility of O_2 and CO_2 in tissue affect the transport of these gases (Diffusion across the alveolar wall).

3.5 Normal breathing:

- The mixture of gases in the alveoli is not the same as the mixture of gases in ordinary air.
- During normal breathing the lungs retain‘s 30% of their volume at the end of each expiration. This is called the *functional residual capacity* (FRC).
- At each breath about 500 cm^3 of fresh air (PO_2 of 150 mmHg) mixes with about 2000 cm^3 of still air in the lungs to result in alveolar air with a PO_2 of about 100 mmHg. (The PCO_2 in the alveoli is about 40 mmHg).
- Expired air includes about 150 cm^3 of relatively fresh air from the trachea that was not in contact with the alveolar surfaces.
- The relation between the inspiration and the expiration is by using the following formula:

The ratio of [CO_2 (output) / O_2 (input)] =Respiratory change ratio or respiratory quotient = R
R is usually slightly less than 1 [$R < 1$].

3.6 During normal breathing:

1. Fresh O_2 diffuse through still air (from the previous breaths) to reach the surface of the alveoli.
2. O_2 is dissolved in the alveolar wall (according to Henry law).
3. O_2 diffuses through into the capillary blood until the PO_2 in the blood = PO_2 in the alveoli = 100 mmHg.

* This process takes less than 0.5 sec.

4. Meanwhile the CO_2 in the blood diffuses even more rapidly into the gas in the alveoli until the PCO_2 in the blood = PCO_2 in the alveolar gas.

3.7 Oxygen transport:

a- <u>Forms of oxygen in blood:</u>

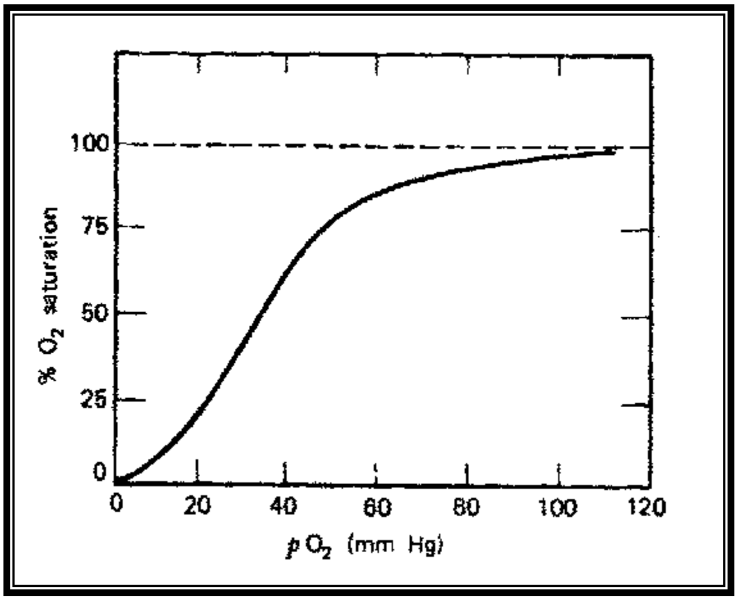
Oxygen exists in blood in two forms:

1. Dissolved O_2 according to Henrys law. The blood can carry only ~2.5 cm^3 of O_2 in solution for each 1 liter.
2. Chemically bound oxygen with hemoglobin. Most of O_2 for the cells is carried in chemical combination with the hemoglobin (Hb) in the red blood cells (RBCs). [1 liter of blood can carry ~ 200 cm^3 of O_2 in solution].

* Most of O_2 is not dissolved; the law of diffusion is altered.

b- Oxygen saturation curve or Dissociation curve:

1. The O_2 will combine with or separate from the Hb in a way that depends on the dissociation curve.
2. The Hb leaving the lung is about 97% saturated with O_2 at a PO_2 = 100 mmHg.
3. The PO_2 has to drop by about 50% before the O_2 load of the blood is noticeably reduced.
4. When the blood reaches the cells and their low PO_2 environment, the O_2 is dissociated from the Hb and diffuses into the cells.
5. Not all the O_2 leaves the Hb; the amount leaving depends on the PO_2 of tissues (that depend on the needing of the tissue). Where the PO_2 decrease in the tissues during exercise causing more O_2 to be dissociate from the Hb and to diffuse into the muscles.
   While under resting condition the venous blood returns to the heart with about 75% of it‘s load of O_2. Why?



During heavy exercise (working muscles)

1. PO_2 in the muscles drops rapidly.
2. PCO_2 will be increased.
3. pH (acidity) will be increased.
4. Temperature of working muscles will be increased.

So, working muscles can obtain 10 times O_2 than consume at rest.

Carbon dioxide (CO_2):

1. The CO_2 - level in the blood is maintained fairly constant by the breathing rate.
2. Excessively rapid breathing (hyperventilation) can lower the PO_2 in the blood.

Carbon monoxide [CO poisoning]:

1. The CO molecules attach very securely to the Hb at places normally used by the O_2.
2. They attach about 250 times more tightly than O_2 and do not easily dissociate into the tissues.
3. The CO inhibits the release of O_2 from Hb.
4. CO can cause death by starving the tissues of O_2.

Treatment:

The CO victim is placed in a hyperbaric O_2 chamber with an absolute pressure (3 atm) of pure O_2, the PO_2 increased by a factor 15. This therapy can not be maintained very long because O_2 poisoning can result.