Respiratory system physiology

sheet handout slides

Number	3
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Inspiration and Expiration

Expiration is normally a passive process. On the other hand, inspiration is an active process; involving muscle contraction and using energy (ATP). This process, which provides the body with the needed oxygen for energy, is efficient that the energy consumed by the respiratory muscles comprises only 2% of the total ATP expense.

According to Ohm's law; flow = pressure difference/resistance. Expiration and inspiration both are examples of flow. When resistance increases, pressure difference must increase to keep the flow constant. Increase the pressure difference means more contraction is needed; which is accompanied with increased ATP consumption. In these settings, oxygen is brought into the body by the action respiratory muscles, and is used during the action of them too! This results with fatigue; since less energy is left for the rest of the body. Normally, the energy consumed by the respiratory muscles does not exceed 5% of the total ATP expense.

In certain pathological cases, expiration becomes an active process, which adds up more energy to the consumed energy by respiratory muscles.

Pulmonary Function Test and Pulmonary Diseases

In the previous lecture, we said that **oxygen** partial pressure is:

- In the inspired air (outside): 160mmHg
- In the ADS: 150mmHg
- In the alveoli: 100mmHg
- In the venous blood: 40mmHg
- In the arterial blood: 100mmHg
- In the interstitial space: 40mmHg
- Intracellular: less than 40mmHg

Pulmonary diseases can be classified into 3 entities:

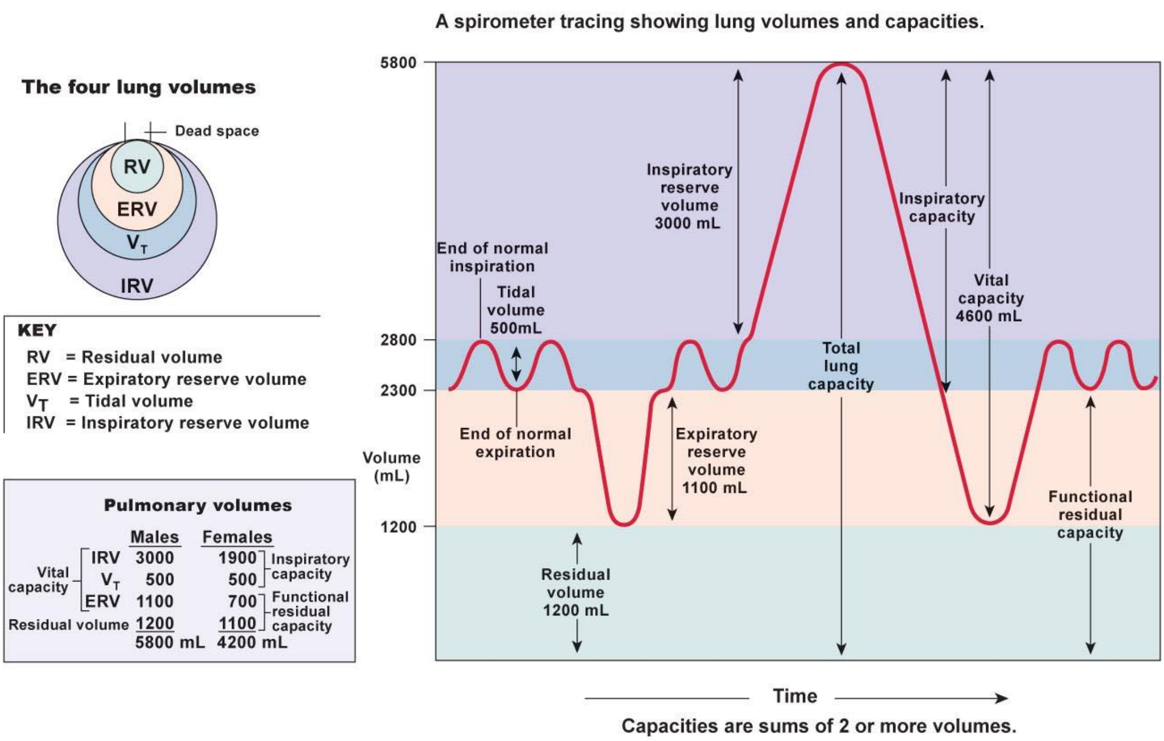
- Obstructive diseases: in the **airways**; 70% of respiratory diseases
- Restrictive diseases: in the **lung**; difficulty in inflation 20-25%
- Vascular: 5-10% of respiratory diseases; pulmonary hypertension is an example

Pulmonary function test is used to diagnose patients with different pulmonary diseases **(vascular diseases are not diagnosed with it)**. It also helps us in predicting the prognosis and progression of the disease with time. Moreover, improvement of the test results after treatment gives an insight about the reversibility of the disease. This test can be used in screening vulnerable groups; such as screening phosphates mines workers who may inhale dust.

It is important to note that screening allows us to detect for the damage before the manifestation of symptoms. This is very important, because, normally, we use one-third of the lung capacity, and developing symptoms is a late point in the disease progression and means that the damage has reached two-thirds of the capacity and prevented compensation.

0:00 – 10:00

We have said in the previous lectures that pulmonary function test reveals 4 volumes and 4 capacities, as follows:



- Volumes (do not overlap): Residual volume; expiratory reserve volume; tidal volume; inspiratory reserve volume.
- Capacities:
  - Functional residual capacity (most important) = RV + ERV
  - Inspiratory capacity = VT + IRV
  - Vital capacity = ERV + VT + IRV
  - TLC = RV + VT + IRV + ERV

The measurement is done using spirometer "*spiro* (Latin) = I breathe". But spirometer measures the air **entering** or **leaving**, so it cannot measure what resides in the lung. So, spirometer **cannot** measure RV and anything related to it (FRC and TLC).

In order to measure RV, we use another method. The Helium dilution method is done as follows:

1- Before inhaling (FRC), the person is asked to breath from a closed bag with a known volume. This bag contains a known concentration of Helium gas. The amount of Helium present equals (the volume of the bag * He concentration). Note that Helium is not absorbed; it does not penetrate the respiratory membrane. Thus, the amount of Helium is constant throughout the process.

2- After 10 to 15 breaths, Helium is said to be distributed equally in the bag and in the respiratory system. The total amount of Helium is not changed (measurement is made after a normal tidal volume is expired):

$$V_1C_1 = V_2C_2 \text{ (conservation of mass)}$$

Where V_1 is the volume of the bag; C_1 is the initial concentration in the bag; V_2 equals V_1 + FRC; and C_2 is the final concentration ($V_2>V_1$; so $C_1> C_2$).

3- We calculate FRC and RV:

$$V_1C_1 = V_2C_2$$

$$V_1C_1 = C_2\,(V_1 + FRC)$$

$$FRC = \frac{V1\,(C1-C2)}{C2}$$

And then; RV = FRC (calculated) – ERV

10:00 – 20:00

Airways Resistance

Airways extend from the trachea 0 to the 23rd generation of the airways till reaching the alveoli. While passing through them, air faces difficulty (resistance), especially in the phase with the least total cross-sectional area.

Normally, resistance is not felt while breathing. Remember Ohm's law:

$$\text{F (respiratory minute ventilation)} = \frac{\text{driving force}}{\text{resistance}} = \frac{\text{pressure difference}}{\text{resistance}}$$

Also remember:

$$R = \frac{8\eta.L}{\pi.r4}$$

So, **only 1mmHg** pressure difference is what is required for normal breathing, while 100mmHg pressure difference is required in the vascular system, because of many factors; including the viscosity of the blood, which is higher than the viscosity of the air.

1st take home massage: Airway resistance is small and **negligible** because we need very small driving force to overcome it.

<u>Resistance distribution along the airways:</u>

- 40% in the larynx and above.
- 40% in the first 4 generations.

- The rest are the small branches, which have the least contribution on resistance; because they have huge cross-sectional area ($R \propto 1/r^4$ and $1/area^2$).

  *Normally, from the 15^{th} generation to the alveoli, resistance is nearly **0**.*

  2^{nd} take home massage: Normally **(physiologically),** *most of the resistance resides in the **largest** airways.*

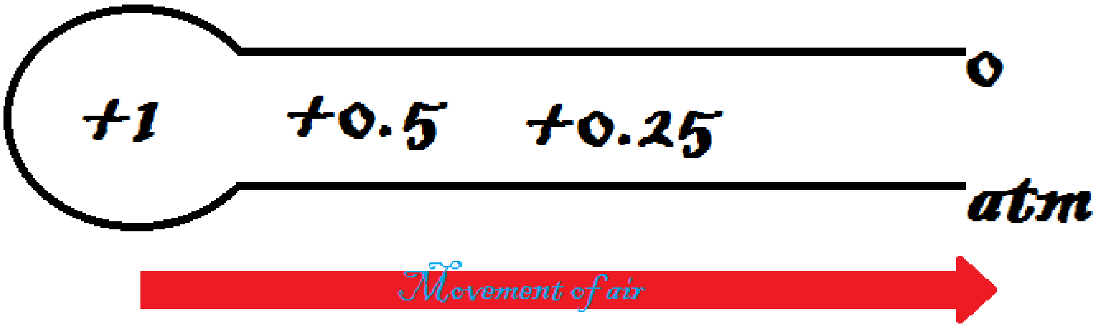
Pulmonary diseases pathophysiology*; Obstructive diseases*

Small airways (12^{th} to 23^{rd}) are more vulnerable to obstruction than the large airways; because:

- They have smaller lumens; excessive mucous secretion can block them
- They have more smooth muscles; bronchoconstriction can narrow them
- Large airways are supported with cartilage; so they are noncollapsable

In obstructive diseases (ex. COPDs), the resistance of the small airways increases, and this results with difficulty in expiration and not inspiration. But why? This is discussed in the following points:

1- Both the alveoli and the small airways are surrounded by the pleural cavity. The normal pleural pressure before the beginning of inspiration is (-4). This pressure is an opening pressure. During inspiration, pleural pressure decreases to (-6); so partially closed airways will be opened.
2- Negative pleural pressure (sub atmospheric) is a pulling or an opening pressure, while positive pleural pressure is a closing pressure.
3- Normally, alveolar (+1) pressure enables the outward movement of air (from highest pressure to lowest pressure).



4- In obstructive diseases, when resistance increases 10x, pressure difference must also increase 10x to maintain constant flow. So, (-4) pleural pressure now becomes (+5). This means compression on the lung. (+5) in expiration is a closing pressure; the partially closed airways will be fully closed in expiration.

5- Now, effort is done by the expiratory muscles to increase the pressure inside the alveoli without closing the airways. But remember that since the alveoli and the small airways are covered with the pleural cavity, compression will affect all of them.

20:00 – 30:00

According to the results of the pulmonary function tests, we can differentiate between the obstructive and the restrictive diseases as follows:

Obstructive diseases	*Restrictive diseases*
Exhaling problems	**Inhaling problems**
TLC is higher than normal	The problem is in the balloon itself (the lung); inflation of the lung is harder; too much bigger force is required to inflate the lung
	TLC is lower than normal

Signs and symptoms

Wheezing

When passing through the obstructed segment, air will flow in *turbulent* manner. This kind of flow is audible, and can be heard as wheezing sound during exhalation (similar to the concept of murmurs in CVS) with or without the stethoscope (according to degree of turbulence).

Sleep problems and pursed lips

We cannot measure the resistance of airways, because 3 constant conditions must be present to be able to do so. (We have to look up these conditions; included in the exam.) Resistance is measured indirectly; according to the driving force of the flow (difference in pressure).

Since resistance increases in obstructive diseases, expiration becomes an active process (see the beginning of the sheet). So, sleeping is affected, because the patient needs to be awake while breathing. The patients may also need to narrow their lips while exhaling; because closing the lips elevates the pressure backwards, which aids in opening the obstructed airways.

COPD, Smoking and Heart

Smoking results with having chronic obstructive pulmonary disease COPD. COPD has two forms: chronic bronchitis and emphysema. These two forms are related; most chronic bronchitis patients have a degree of emphysema, and most patients with emphysema have some sort of chronic bronchitis. Pure cases of these two forms comprise less than 1% of COPD cases; in which the cause is genetic defects in certain enzymes.

Generally, a lung disease can result with heart problems, and vice versa. In COPD, the heart is also affected. COPD can result with right heart failure. Generally, lung diseases (obstructive or restrictive) result with right ventricle dilation with/without right ventricular failure, this is called Cor pulmonale (it's an alteration in the structure and function of the right ventricle (RV) of the heart caused by a primary disorder of the respiratory system). "With/without right ventricular failure" means that if the patient does not have RVF, they have a high risk of getting it soon.

So, smoking results with COPD, and COPD leads to RHF. (RHF will be explained later.)

Sorry for the mistakes