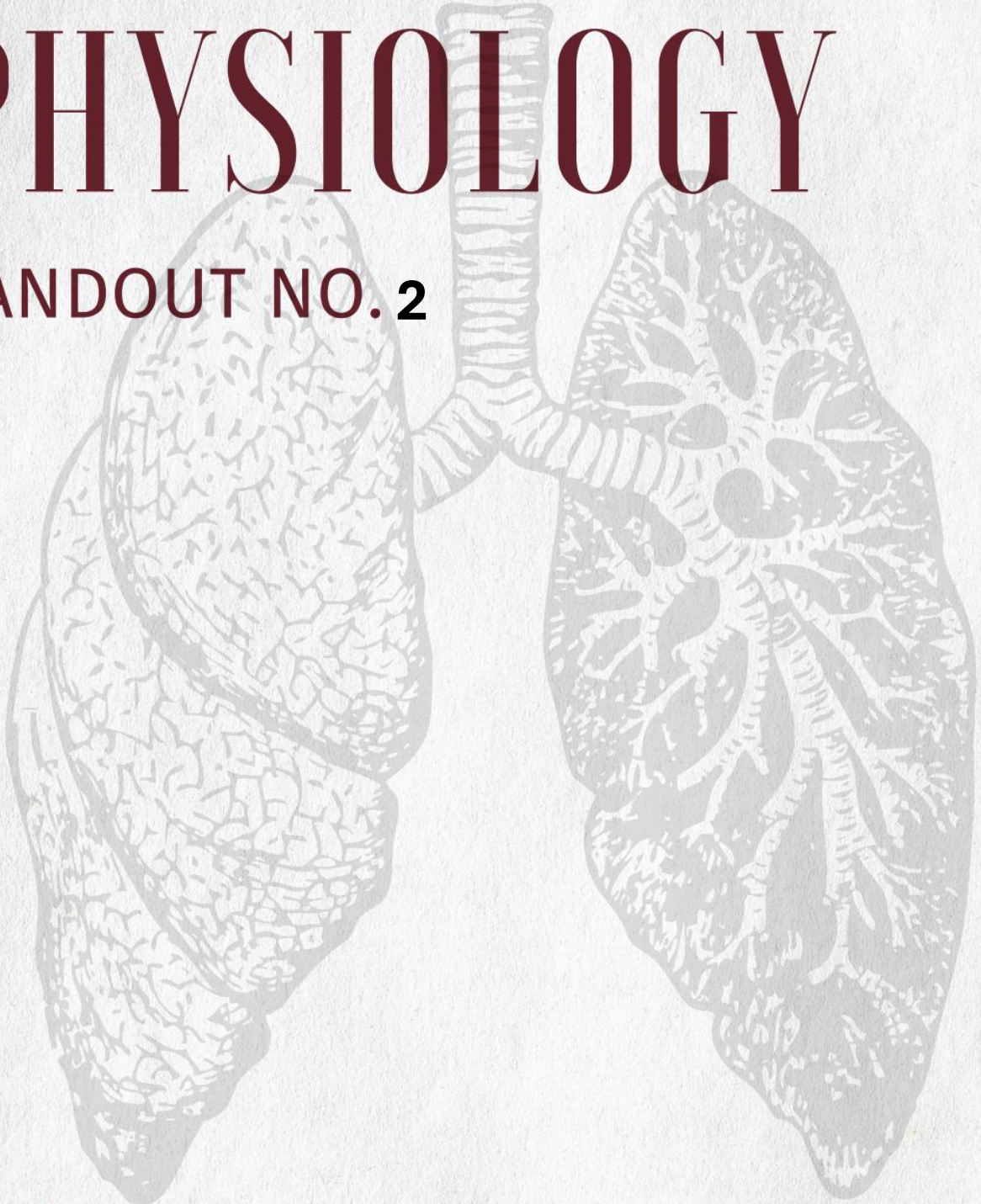
RESPIRATORY SYSTEM

PHYSIOLOGY

HANDOUT NO. 2



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important

Revision from the Previous Lecture

We consider the trachea generation/branch/division 0, meaning that we still didn't begin dividing into branches.

The doctor answered a student's question below:

A: This is important to know, and you have to memorize the numbers:

The blood volume forms 7% of the body's weight in males (if body weight was 70 kg), and 6% in females. This approximates 5000ml which is distributed throughout the CVS as follows: 3000ml in systemic veins (60%), 750ml in systemic arteries (15%), 450ml in pulmonary circulation (9%), 350ml in the cardiac chambers (7%), and 350ml in systemic capillaries (7%) [Doc said this one is particularly important to him].

Now, in the lung, blood is found in 3 regions, 190ml in pulmonary arteries, 190ml in pulmonary veins, and 70ml in pulmonary capillaries. Alveoli have about 2500ml inside! So, when equilibrium occurs, we can expect the small component (pulmonary capillaries) to become like the bigger one (alveoli), without a change in the bigger one because we're not talking about equal volumes. If we were, we'd simply say (100 + 40)/2 = 70.

Extra explanation: In the lungs: Blood volumes are distributed as 190 ml in pulmonary arteries, 190 ml in pulmonary veins, and 70 ml in pulmonary capillaries.

- The alveoli, which are the tiny air sacs for gas exchange, contain 2500 ml of air.

What Happens During Equilibrium?

- When gases like oxygen or carbon dioxide equilibrate, the small volume of blood in the pulmonary capillaries (70 ml) adjusts to match the gas partial pressure in the large alveolar air volume (2500 ml).

- The larger alveolar air volume doesn't significantly change because it's much bigger than the capillary blood volume.

So, It is not about the two having the same volume. Instead, it's about the partial pressures of gases becoming equal (e.g., oxygen levels in the blood matching oxygen levels in the alveolar air).

If it were about equal volumes, you could calculate an average, like (100+40)/2=70. But here, the focus is on partial pressure, so the alveolar air sets the tone for the smaller capillary blood.

Now we'll do minor calculations regarding TBW (total body water):

Systemic capillaries comprise 60% TBW in males (and 55% in females – because they have more fat so there is less water => fat hates water). So: 60% x 70 kg (body weight) = 42L.

The 42L are divided into:

a. 2/3 represent 28L that go to the intracellular fluid

b. 1/3 represent 14L that is divided into 2 further parts in the extracellular fluid:

i. interstitial fluid taking 11L (this what we care about)

ii. plasma taking 3L

Let's recall those pulmonary capillaries we mentioned before! Systemic capillaries had 350ml inside, with the interstitial fluid we have 11000ml! So most probably the smaller component will become like the bigger one and attain a pO2 of 40 mmHg.

- **Another concept:** The pressure inside the alveoli is constant at 100 because of continuous gas exchange (oxygen entering equals oxygen leaving).
- In cases of pulmonary embolism: There is no exchange with the blood, so oxygen is not being lost.

* The PO_2 rises to 150, matching the partial pressure in the anatomical dead space (ADS), as it cannot exceed 150.When blood flow returns, gas exchange resumes, and the PO_2 returns to 100.

Revision Done

Now we will start our new lecture

The Most Important Law to remember is **Ohm's Law,** which states that flow is directly proportional to the driving force, but inversely proportional to the resistance.

$$Flow \propto \frac{Driving\ Force}{Resistance}$$

We will now discuss the concept of how breathing happens through inspiration, which is the inflow of air from A (trachea for example) to B (alveoli). The opposite is expiration; the outflow of air from B to A.

To begin with, atmospheric pressure at point A is 0 mmHg, and the alveolar pressure is also zero.

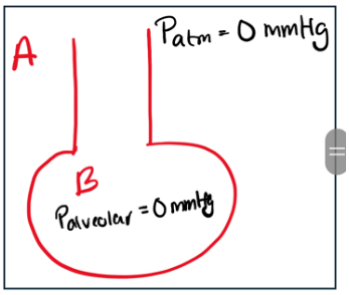
Flow = (Patm – Palveolar)/Airway Resistance.

- Airway resistance is the total of resistances from the mouth up to the alveoli. These resistances are connected in series. It's basically like TPR (from CVS). So, the driving force here is 0 and so there's no flow.

To generate flow, we have 2 options:

1. Make the Patm higher, like +1 mmHg for example. (P atm>P alveolar)

2. Make Palveolar lesser than Patm!



If we work on option 1 and we make Patm positive, this is called positive pressure breathing (making one end positive). and it's done using an endotracheal tube and attaching it to a respirator (like in the ICU). This pattern of breathing isn't physiological, but artificial as we cannot manipulate Patm.

Option 2 is the physiological way. It's done by reducing Palveolar below Patm. It's called negative pressure breathing. How do we do that?! This is done by using **Boyle's Law** which states that in a closed chamber with maintained temperature, P1 *V1=P2* V2. It's also represented by PV= C where C is constant.

Let's take pressure to be 3 and volume to be 4, PV=C is 3x4=12. So, if we want to reduce P, we have to increase V to get the same C as so: 2x6=12. This means that to make the intra-alveolar pressure less, we have to increase the volume. Recall that P=F/A. A = the area, F = the Force which represents the number of gas molecules inside the alveolus, they hit the wall continuously and produce pressure. If the same force is in a larger area, pressure will decrease. To solve this problem, we have to increase the volume of the lung, **but how can we increase the volume of the lungs?**

The lung is surrounded by the intrapleural cavity with a pressure of –4. If we can get it to be –6, the lung will automatically inflate. Be careful that we make it MORE negative, not negative (It is already negative, so we make it more negative, like from -4 to -6). **But now how do we make it more negative?**

When the diaphragm contracts, it descends and increases the thoracic cage volume, whereas the abdominal cavity volume becomes less. The thoracic cage pressure becomes more negative, and the abdominal cavity pressure becomes more positive, pushing against the veins and increasing the venous return (recall CVS physiology) All this happened because of the contraction of the diaphragm. **To sum up, the sequence of events is as follows:**

1. The diaphragm contracts.
2. Thoracic cage volume increases.
3. Decreased intra-thoracic/intra-pleural/intra-alveolar/intra-pulmonary pressure after the lungs have inflated. (Become more negative)
4. After we achieve a more negative pressure, air finally enters.

Keep in mind that the inflated lung drives air in, not the other way around! A question can come asking you to arrange the events in order of what happens first.

الرئة المنفوخة هي التي سحبت الهواء، ليس الهواء من نفخ الرئة!

Inspiration vs. Expiration

- **Inspiration** is an active process because it requires the contraction of the diaphragm which in turn requires ATP and O2. From the total ATP usage of the body, this contraction uses only 2% (some books say up to 5%), leaving 98% for the rest of the body and deeming it a very efficient machine.
- **Expiration**, on the other hand, is passive. At the **end** of inspiration, the intra-alveolar pressure becomes 0 mmHg which is atmospheric! But **During** inspiration, however, the intro-alveolar presser is sub-atmospheric which makes sense! That is why the air is still flowing to inside (from higher pressure to lower pressure). After the diaphragm relaxes, the intra-thoracic pressure becomes less negative (from –6 to –4, so it increases by 2!). This compresses the lungs, the area is smaller now, so the pressure inside the lungs is larger and the air will move outside. That makes **expiration passive** (doesn't involve contraction of any muscle! It takes relaxation of contracted muscle, the diaphragm)

التيكت دفعناها بالروحة، الرجعة كانت free :)

Understanding Flow and Resistance in Physiology

Key Concepts

- **Flow Equation:** Flow (ΔF) = Driving Force / R, where Driving Force is the pressure difference and R is the resistance.
- **Cardiac Example:** If we consider the heart's flow from the left ventricle to the right atrium:
    - Pressure in the aorta (Pa) = 100 mmHg
    - Pressure in the right atrium (PRA) = 0 mmHg
    - Driving Force = Pa - PRA = 100 mmHg
    - Flow (ΔF) = Driving Force / TPR (Total Peripheral Resistance)

Total Peripheral Resistance (TPR) relates to flow, and flow equates to Cardiac Output (CO). At rest:

- **CO = 5 L/min**
- **Respiratory Minute Ventilation (RMV) = 6 L/min**

While CO and RMV values are close, the driving forces (Driving Force) differ significantly:

- In the heart, Driving Force = 100 mmHg
- In the respiratory system (RS), Driving Force = ±1 mmHg

Measuring Resistance

Resistance can be determined **directly** or **indirectly**:

1. **Direct Measurement:** Using **Poiseuille's Law**, which requires:
    - Laminar flow (not turbulent)

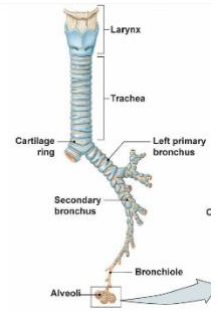
- Homogeneous fluid (e.g., water) not heterogeneous as the blood (contains plasma and RBCs)
- Steady, non-pulsatile flow (steady flow with respect to time)

These conditions are not typically met in physiological systems (e.g., blood flow in vessels), so Poiseuille's Law is often not applicable in these contexts. Instead, it is more suited to systems like water pipes.

2. **Indirect Measurement:** Calculated by knowing flow (ΔF) and the pressure difference (Driving Force).

Airway Resistance Compared to Total Peripheral Resistance (TPR):

- Resistance can be identified by the amount of Driving Force needed to overcome it. If a small force is sufficient, resistance is low. If a large force is required, resistance is high.
- In arteries, the pressure at the start is 100 mmHg, and at the end is 85 mmHg. In arterioles, the pressure at the start is 85 mmHg, and at the end is 40 mmHg. The difference of 45 mmHg demonstrates the significant resistance faced to push the same amount of blood. Most of TPR resides in the arterioles due to the largest pressure drop across them.



$R \propto \frac{1}{r^4}$

- **The resistance is inversely proportional to r^4.** This means even a small change in radius leads to a significant change in resistance.
- If the resistance increases tenfold, we have to maintain the same flow! We cannot compromise flow, as this could lead to complications such as dyspnea, hypoxia, etc. Therefore, to overcome resistance in bronchioles, delta P (the driving force) must be increased ten times—meaning instead of a pressure of -1 mmHg, it must be -10 mmHg.
- Looking at a structural aspect, the trachea is surrounded by cartilage, which is a bony material that keeps it non-collapsible up to generations 10 to 12, where remnants of cartilage remain. Beyond 12 generation, they are left in their own! Airways diameter is so small and surrounded by smooth muscle cells, which can contract in response to irritation or resistance. Additionally, excess mucus secretion can lead to obstruction in that level, but this is unlikely at the tracheal level as it remains open even though there is small amount of mucus. However, if obstruction reaches generation 13 or 14, it will affect everything forward to that point.

From that, I have 3 possibilities that can cause hypoxia, meaning a decrease in oxygen utilization by the cells:

1. Unavailability of oxygen from the outside
2. Increased airway resistance (the bronchioles are closed)
3. Stiffness in the alveoli—rigid, non-compliant, non-inflatable balloon

Mentioned in the slides: - inadequate oxygenation of lungs
• Atmosphere… high altitude • decrease muscle activity ..paralysis
-pulmonary disease
-inadequate transport… anemia and heart failure
-inadequate usage as septicemia and CN poisoning

Lung Diseases Categorized:

1. **70% Obstructive:**
    - The most common, e.g., COPD (Chronic Obstructive Pulmonary Disease)
2. **20% Restrictive:**
    - Issues in the alveoli itself, such as excess fibrosis or infiltration, preventing proper inflation. Airways are patent (no issues there).
3. **10% Vascular:**
    - Problems in the respiratory membrane (capillaries), affecting gas exchange.

Obstructive vs. Restrictive Diseases:

- In **obstructive** diseases:
    - Normally, expiration is a passive process where the diaphragm relaxes. However, in obstructive diseases, passive expiration is insufficient because a driving pressure of +1 in expiration is not enough. Instead, a pressure of +10 is needed. To generate this higher pressure, expiratory muscles such as the internal intercostal muscles must actively compress the lungs.
    - This creates a problem: increased intrapleural pressure becomes positive, which pushes against the bronchioles. This can lead to airway closure (closing pressure), making expiration difficult for patients.
    - Inspiration is not problematic. Patients can utilize additional inspiratory muscles, such as the external intercostal muscles, to aid in inhalation.
    - During expiration, airflow through narrowed airways becomes turbulent instead of laminar, producing sounds known as **wheezing**. Hearing wheezing indicates the presence of airway obstruction.
    - To sum up, the **patient faces problems during expiration**
    - Patients can easily inhale, but they struggle to exhale, leading to retention of air in the lungs (the patient can enter the air but can't get it out!) —this condition is known as emphysema=> انتفاخ الرئة
    - Total Lung Capacity (TLC), which represents the total volume of air in the lungs, increases from the normal 5L to around 7L.
- In **restrictive** diseases:
    - Cause **problems with inhalation (inspiration).**

- In restrictive diseases like pulmonary fibrosis, patients experience difficulty in inhalation, and Total Lung Capacity (TLC) decreases significantly to around 4 or 3.5L, compared to the normal 5L.

Through pulmonary function tests, we can determine which category the patient belongs to—whether obstructive, restrictive, or vascular.

Important Notes

- In physiology, resistance is rarely measured using Poiseuille's Law due to the absence of its required conditions (laminar, homogeneous, steady flow).
- Physiological resistance is better understood through indirect methods, ensuring accuracy in the context of complex, pulsatile, and turbulent systems like blood circulation.
- Expiration is passive normally

Version 2:
- Reorganisation of the information from the slides on page 6
- Partial pressure instead of concentration (bcz they are gases not ions) on p2