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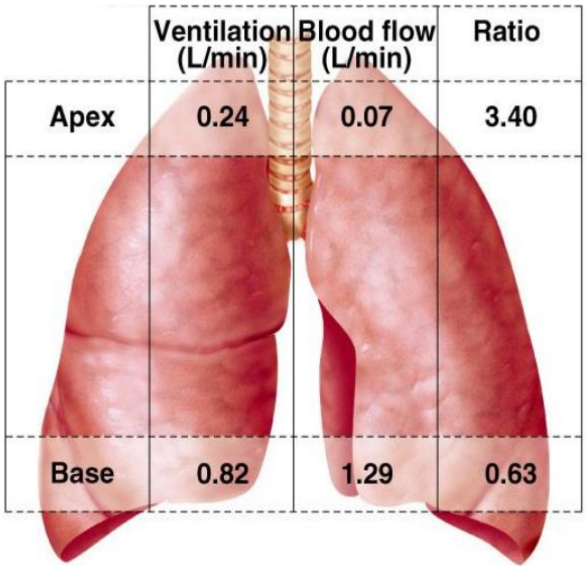
اللهم ارحمه واغفر له وأكرم نزله ووسع مدخله، لا تنسوه من دعائكم، إنا لله وإنا إليه راجعون.

#فريق_دوبامين_العلمي

Respiratory System Physiology

Comprehensive File 7

Dr. Yanal Shafagoj



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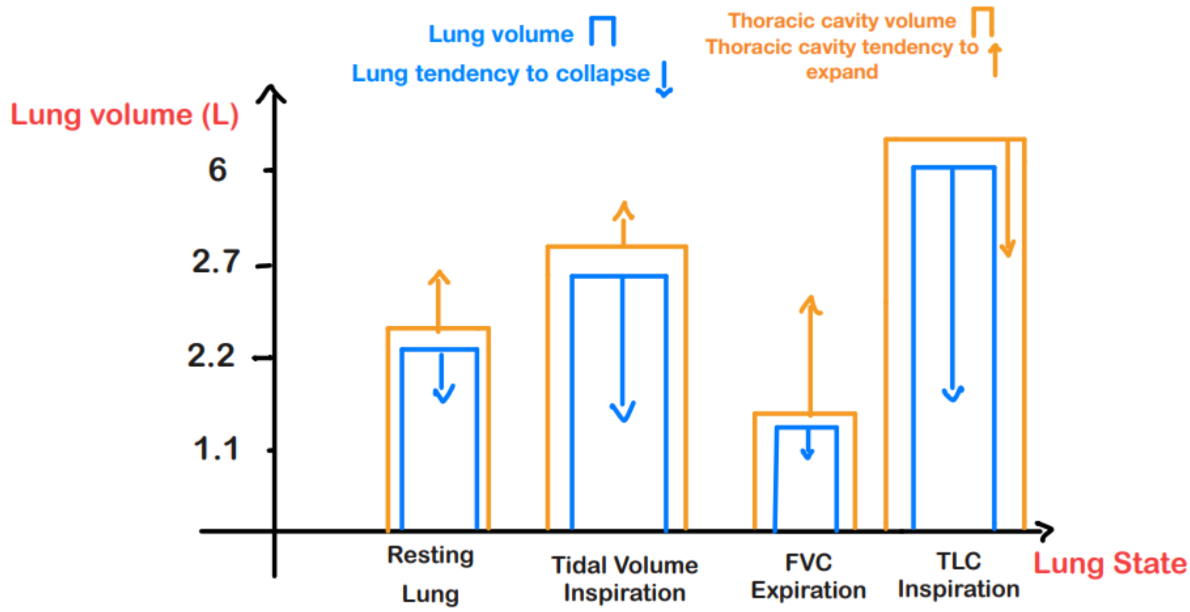
Lung – Thorax System

The lung is an elastic balloon, partially inflated at an FRC of 2.2 L, even when the airways are open. This is achieved by the presence of surrounding negative pressure. In the case of pneumothorax, as seen in surgery, stab wounds, or gunshot wounds, when air enters the pleural cavity, this negative pressure disappears, and the lung reaches its resting volume. This resting volume is different from residual volume. Under physiological conditions, we do not reach the resting volume (150 ml); we only reach residual volume (1.1 L).

To describe the relationship between the two opposing forces acting on the lung, we examine the state of the lung at different volumes, as shown in the following figure.



At an FRC of 2.2 L, the lung has a tendency to collapse, while the thorax has a tendency to expand as it tries to reach its resting volume (approximately 75% of total lung capacity, ~4.5 L). At this point, the lung–thorax system is in equilibrium.

To change the state of the elastic lung, an external force must be applied. Inspiration is achieved through expansion of the thorax by the inspiratory muscles. After inspiration, the thoracic tendency to expand decreases, while the tendency of the lung to collapse increases. The system therefore tends to collapse, and expiration is passive.

After forced vital capacity (FVC) expiration using expiratory muscles, reaching the residual volume of the lung, the tendency of the lung to collapse decreases, while the tendency of the thorax to expand increases. The lung–thorax system therefore tends to expand. In this state, expiration is active, while inspiration is passive.

After full inspiration reaching total lung capacity, the lung has a very strong tendency to collapse, and the thorax also tends to collapse as it attempts to return to its resting volume. Therefore, the entire lung–thorax system has a strong tendency to collapse.

To summarize, using the numbers in the example:

Lung Volume (ml)	Lungs Tend to	Thorax Tends to	System Tends to	Inspiration is	Expiration is
4500-6000	Collapse	Collapse	Collapse	Active	Passive
4500	Collapse	-	Collapse	Active	Passive
2200-4500	Collapse	Expand	Collapse	Active	Passive
2200	Collapse	Expand	-	Active	Active
150-2200	Collapse	Expand	Expand	Passive	Active

All intervals are not inclusive, meaning that borderlines are not part of either interval.

Medicolegal Application of Resting Lung Volume

Stillbirth
In stillbirth, the infant is delivered without ever breathing. The lungs remain in their fetal state: fluid-filled and collapsed, with no air entering the alveoli. Because respiration never occurs, no resting air volume is established in the lungs, and their density remains high.

Consequence in stillbirth lungs
Since there is no retained air (effectively 0 mL), the lungs remain heavy and solid. Even when the lungs are cut into pieces, no air escapes, and the lung tissue sinks when placed in water.

Live birth
In a live-born infant, breathing occurs after delivery. Even a few effective breaths introduce air into the alveoli, and not all of this air is expelled during expiration. Approximately 150 mL of air remains in the lungs at rest, keeping alveoli partially expanded and reducing lung density.

Medicolegal relevance
The lung floatation (hydrostatic) test is based on this difference. Lungs that float indicate the presence of retained air and therefore respiration, suggesting live birth. Lungs that sink indicate absence of retained air and are consistent with stillbirth, making the test useful in medicolegal determination of whether a newborn was born alive or dead.

The Ventilation-Perfusion Ratio

Defining Ventilation and Perfusion

Alveoli receive both air and blood; air Is supplied by the airways, while blood is supplied by means of the pulmonary circulation that finally reach capillaries for gas exchange.

Typical values for total alveolar blood perfusion are approximated by the cardiac output, which is around 5 L/min for an adult at rest.

$$\dot{Q}_A = 5\,\frac{L}{min}$$

For air ventilation that reaches the alveoli, remember that only 350 ml of the 0.5 L-tidal volume reaches the alveoli, while the remaining 150 ml are for the dead space.

$$\dot{V}_A = 350\,\frac{ml}{breath} * 12\,\frac{breaths}{min} = 4.2\,\frac{L}{min}$$

*The **dot** on V and Q indicate that the quantity is a **volume per unit time (flow).***

What is the ventilation-perfusion ratio?

Dividing V over Q gives the ventilation perfusion ratio, which is 0.84 in the example above (0.8 is used for approximation). This number is dimensionless and refers to the total lung V/Q in ideal scenarios. The alveolus-specific values differ based on the location of the alveolus – basal or apical.

Ventilation (V) varies in accordance with the intrapleural pressure surrounding the specific location of the alveolus. Apically, the intrapleural pressure is about -8 mmHg, while it is -2 mmHg basally. This means that apical alveoli are under higher inflation pressure and are thus more inflated in comparison with basal ones. This makes the basal alveoli more compliant and thus can receive more ventilation.

$$\boldsymbol{\dot{V}_{Base} > \dot{V}_{Apex}}$$

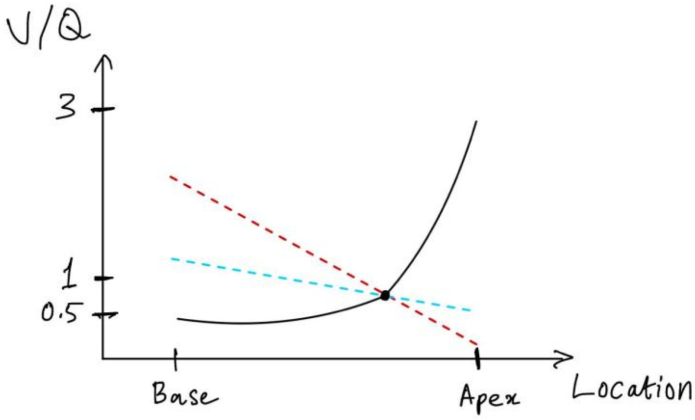
Perfusion (Q) is governed by the ability of blood to reach the specific location in the lungs. Due to gravity, the basal alveoli are more perfused compared to apical ones.

$$\boldsymbol{\dot{Q}_{Base} > \dot{Q}_{Apex}}$$

Although both V and Q behave similarly with regional variation, the V/Q ratio is not constant. It was found that V/Q ratio is higher in the apex than in the base. This can be mathematically inferred given that the decreasing perfusion slope from base to apex is steeper than the decreasing ventilation slope from base to apex.

The V/Q ratio is significantly increased as we move from base (≈0.5) to apex (≈3).

The following graph illustrates the 3 graphs (V, Q, and V/Q):



Effect of V/Q Ratio on Post-Alveolar PO_2

Considering the **apex**, there is 3 times more air than blood arriving at the alveoli for gas exchange **(V/Q > 1).** This causes relatively extra oxygen to reside in the alveoli. So, instead of the typical 100 mmHg, the accurate number is around 130 mmHg. This directly translates to the post-capillary PO_2, which reaches 130 mmHg and then enters the equilibrium state with alveolar oxygen, as discussed earlier.

Considering the **base**, there is 2 times more blood than air arriving at the alveoli for gas exchange **(V/Q < 1).** This causes relatively less oxygen to reside in the alveoli (around 90 mmHg). This also directly translates to the post-capillary PO_2.

Tuberculous bacilli are aerobic bacteria, and thus they reside in the apex, where oxygen is plenty, so whenever X-ray shadows are seen in the apical region, TB is suspected. However, basal shadows indicate other pathological conditions, such as malignancies, not TB (low O_2).

There are more basal alveoli than apical ones (about 3 times more). So, when all oxygenated blood from all parts of the lungs arrives at the left atrium, the mixing gives 95 mmHg as ABG that will be pumped to the whole body for cellular use.

Using a weighted average with weights 3 and 1 for basal and apical, respectively, the ABG should be 100 not 95 mmHg. However, the physiologically accurate number is 95. The reason behind this shall be discussed later.