

HUMAN ANATOMY AND PHSYIOLOGY-II

UNIT-III

TOPIC: Lung Volumes and capacities



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LUNG VOLUMES:

Pulmonary function can be examined by the spirometry technique. Spirometers are the traditional tools of the respiratory physiologists. The subject breathes into a closed system in which air is trapped (bell). As the subject breathes air movement into or out of the mouthpiece causes the bell to rise (inspiration) or fall (expiration). Corresponding movements of an attached pen register the change in volume on a rotating drum recorder. From such a recording we could measure

Tidal volume (TV): Volume of air inhaled or exhaled with each breath during normal breathing (0.5 L).

Inspiratory reserve volume (IRV): Maximal volume of air inhaled at the end of a normal inspiration (3 L)

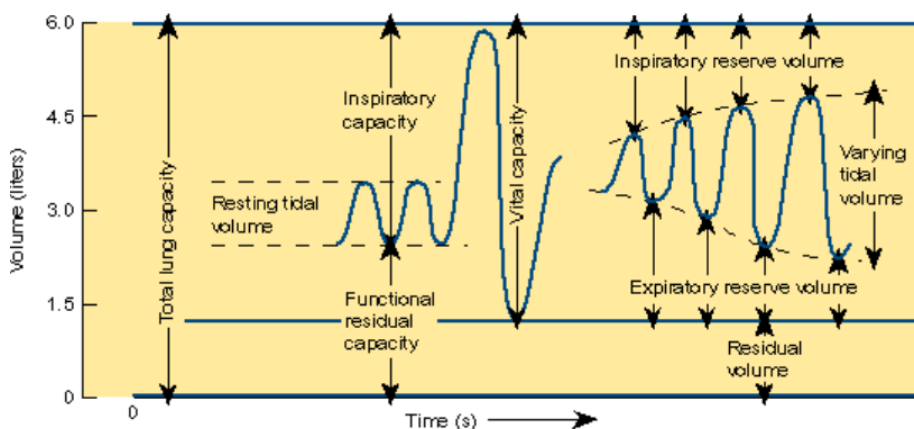
Expiratory reserve volume (ERV): Maximal volume of air exhaled at the end of a tidal volume (1.2 L).

Inspiratory capacity (IC): Maximal volume of air inhaled after a normal expiration (3.6 L)
(TV+IRV)

Functional Residual Capacity (FRC): The volume of gas that remains in the lung at the end of a passive expiration. (2-2.5 L or 40 % of the maximal lung volume) (ERV+RV).

Residual Volume (RV): The volume of gas remains in the lung after maximal expiration. (1-1.2 L)

FRC and RV can not be measured with an ordinary spirometer (For details see below).



Total Lung Capacity (TLC): The maximal lung volume that can be achieved voluntarily. (5-6 L)

(IRV+ERV+TV+RV)

Vital capacity (VC): The volume of air moved between TLC and RV. (4-5 L) (IRV+ERV+TV).

Multiplying the tidal volume at rest by the number of breaths per minute gives the total minute

volume (6 L/min). During exercise the tidal volume and the number of breaths per minute increase to produce a total minute volume as high as 100 to 200 L/min.

Measurements of Functional Residual Capacity (FRC) and Residual Volume (RV): There are two techniques to study these volumes:

Helium Spirometry: In this technique a subject is connected to a spirometer filled with helium which

is virtually insoluble in the blood. After some breathes the amount of helium in the lung and the spirometer reach equilibrium. Because there is no loss of gas during the experiment the amount of helium before ($C_1 \times V_1$) and after the equilibrium ($C_2 \times [V_1 + V_2]$) is same.

$$V_1 = C_2 \times (V_1 + V_2)$$

$$V_2 = V_1 \times (C_1 - C_2) / C_2$$

$$V_2 = \text{FRC}$$

Another way of measuring FRC is with a body plethysmograph. It is a big airtight box in which the subject sits. At the end of a normal expiration, the mouthpiece is shut and the subject makes respiratory efforts.

When the subject makes an inspiratory effort against a closed airway s/he slightly increases the volume of his/her lung, airway pressure decreases and the box pressure increases:

$$P_1 \times V_1 = P_2 \times (V_1 - \Delta V)$$

The pressure in the box before (P_1) and after (P_2) the respiratory efforts,

V : Volume in the box before the respiratory efforts and ΔV can be measured.

The Boyle's law can also be applied to the gas in the lung:

$$P_3 \times V_2 = P_4 \times (V_2 + \Delta V)$$

$$V_2 = \text{FRC}$$

$P_3, 4$: Mouth pressures before (P_3) and after (P_4) the respiratory efforts.

If the measurement is done following a forced expiration

$$V_2 = \text{RV}$$

In contrast to the helium technique, which measures only the ventilated air, the body plethysmograph measures the total volume in the gas in the volume including the gas trapped in the airways (if there is any). Normally measurements with these techniques are similar. However, the difference is increased in the presence of lung diseases.

TOTAL VENTILATION: The total volume of the gas leaving the lung per unit time. If TV is 500 ml and there are approximately 15 breaths/min the total volume of the gas leaving the lung, total ventilation will be $500 \times 15 = 7500$ ml/min. It can be measured by having the subject breath through a valve that separates the inspired air from expired air and collecting the expired air.

ALVEOLAR VENTILATION: The volume of the gas reaching the respiratory zone of the airways.

However, not all of the total ventilation volume reaches the alveoli. 150 ml of the TV (500 ml) is left behind in the airways, which does not contain alveoli, therefore does not contribute the diffusion

(Anatomic death space). Thus, the volume of gas entering the respiratory zone, alveolar ventilation, is

$(500-150) \times 15 = 5250$ ml/min. The measurement of alveolar ventilation is more difficult. One way is to measure the volume of anatomic dead space and calculate the dead space ventilation. This then subtracted from the total ventilation.

Alveolar ventilation = Total ventilation – Anatomic death space ventilation

Anatomic dead space ventilation = Anatomic dead space volume x respiration frequency

VE: total expiration volume

VT: Tidal volume

VD: Dead Space volume

VA: volume of alveolar gas during tidal breathing

V: volume per unit time

$VT = VD + VA$

$(VT \times n) = (VD \times n) + (VA \times n)$

V: volume per unit time

VE: Expired total ventilation

VD: dead space ventilation

VA: alveolar ventilation

$VE = VD + VA$

$VA = VE - VD$

The disadvantage of this method is it is not very easy to determine dead space volume without a considerable error.

Another way of measuring the alveolar ventilation is from concentration of CO₂ in expired air. Since The amount of CO₂ in the inspired air is negligible and no gas exchange occurs, we could assume that there is CO₂ in the anatomic dead space. Therefore CO₂ in the expired air comes from alveoli.

$VCO_2 = VA \times \% CO_2 / 100$

VCO₂ = the volume of CO₂ exhaled per unit time.

$VA = (VCO_2 \times 100) / \% CO_2$

$\% \text{ CO}_2 = \text{Fractional CO}_2 \text{ concentration} = \text{FCO}_2$

ANATOMICAL DEAD SPACE: Volume of the conducting airways. It is approximately 150 ml but its volume increases with large inspiration and depends on the size and the posture of the subject.

Measurement of dead space: Fowler's method: The subject breaths pure oxygen through a valve box and a rapid nitrogen analyser samples and measures the nitrogen concentration in the expired air. After a single inspiration of pure oxygen (100 %) nitrogen concentration in the expired air is increased as the gas in the dead space is washed by pure oxygen. Nitrogen concentration quickly reaches a plateau level (alveolar plateau). The dead space is found by plotting nitrogen concentration against the expired volume. The expired volume up to the vertical line drawn such that area A = area B represents the anatomical dead space volume

TESTS OF VENTILATORY CAPACITY

Forced Expiratory Volume (FEV): It is the volume of gas exhaled in one second by a forced expiration following a full inspiration (FEV1). The total volume of the gas exhaled after a full inspiration represents the vital capacity. However, this value could be slightly smaller than the vital capacity measured with a slow (normal speed) expiration. Therefore, this value is called forced vital

capacity (FVC). The normal ratio of the FEV1 is 80 % of FVC.

Forced Expiratory Flow (FEF25-75): This measurement represents the expiratory flow rate over the middle half of the FVC (between 25 – 75 %). It is obtained by identifying the 25 % and 75 % volume points of FVC, measuring the time between these points and calculating the flow rate.

Interpretation of tests of forced expiration: On the basis of the knowledge obtained from these functional tests, lung diseases can be classified as restrictive or obstructive. In restrictive lung diseases (such as pulmonary fibrosis), the vital capacity is reduced to below normal levels. However, the rate at

which the vital capacity is forcefully exhaled is normal. In obstructive lung disease (such as asthma, emphysema, bronchitis) the vital capacity is normal because lung tissue is not damaged and its compliance is unchanged. In asthma the small airways (bronchioles) constrict, bronchoconstriction increases the resistance to airflow. Although the vital capacity is normal, the increased airway resistance makes expiration more difficult and takes longer time. Obstructive disorders are therefore

diagnosed by tests that measure the rate of forced expiration, such as the FEV1 and FEF25-75. A significant decrease in these values suggests an obstructive lung disease.