THE LUNG VOLUMES AND CAPACITIES

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THE LUNG VOLUMES

- A lung volume is a subdivision of the total capacity of the lungs.

- They are measured when the lungs are in the *midthoracic position* (at the end of a normal resting expiration)

- Their values normally vary with age and sex, being 20 *-25 %* less in females, and even more in old age except the residual volume

- The various lung volumes and their average normal values in young adult males include the following

1- TIDAL VOLUME (TV)

❑This is the volume of air that moves into the respiratory passages (i.e. inspired or expired) in a single breath cycle during *eupnea* (= normal resting quiet breathing). *The average TV is 500 ml.*

2- INSPIRATION RESER VE VOLUME (IRV)

❑This is the volume of air that can be inspired by a maximal inspiratory effort (i.e. by the deepest possible inspiration) *after the end of a normal resting inspiration* (i.e. in excess of the TV). *The average IRV is 3000 ml.*

3- EXPIRATORY RESERVE VOLUME (ERV)

❑This is the volume of air that can be expired by a maximal expiratory effort (i.e. *by* the deepest possible expiration) *after the end of a normal resting expiration* (i.e. in excess of the TV). *The average ER V is 1000 ml.*

4- RESIDUAL VOLUME (IRV)

❑This is the volume of air that *remains in the lungs after the end of a maximal expiration .* Its average value is *1200 ml,* and it can be expelled out of the lungs *only after their collapse (e.g. after opening of the chest)*

The minimal air (or volume) and its clinical importance

- After opening of the chest, however, about 150 ml of air still remain in the lungs.

- This is called *minimal air or volume,* and it is *used medicolegally* in detecting *whether a newly born dead baby had died before or after delivery.*

- This is known by placing a piece of the baby's lung in water. If it floats, it indicates presence of the minimal air (i.e. the baby was born alive and breathed then died).

- On the other hand, if it sinks, it indicates absence of the minimal air (i.e. the baby was born dead and had never breathed)

THE LUNG CAPACITIES

❑A lung capacity comprises *2 or more lung volumes·.* The various lung capacities and their average normal values *in young adult males* include :

1-INSPIRATORY CAPACITY

❑The IC is the volume of air that can be inspired by *a maximal inspiratory effort after the end of a normal resting expiration.* It equals the *T V*+ *IR V* = about *3500 ml.*

2-EXPIRATORY CAPACITY

- The EC is the volume of air that can be expired by *a maximal expiratory effort after the end of a normal resting inspiration.* It equals the *TV*+ *ERV* = *about 1500 ml*

3. FUNCTIONAL RESIDUAL CAPACITY

- This is the volume of air that *remains in the lungs after the end of a normal resting expiration.* It equals the *ERV* + *R V* = about *2200 ml.*

4. VITAL CAPACITY

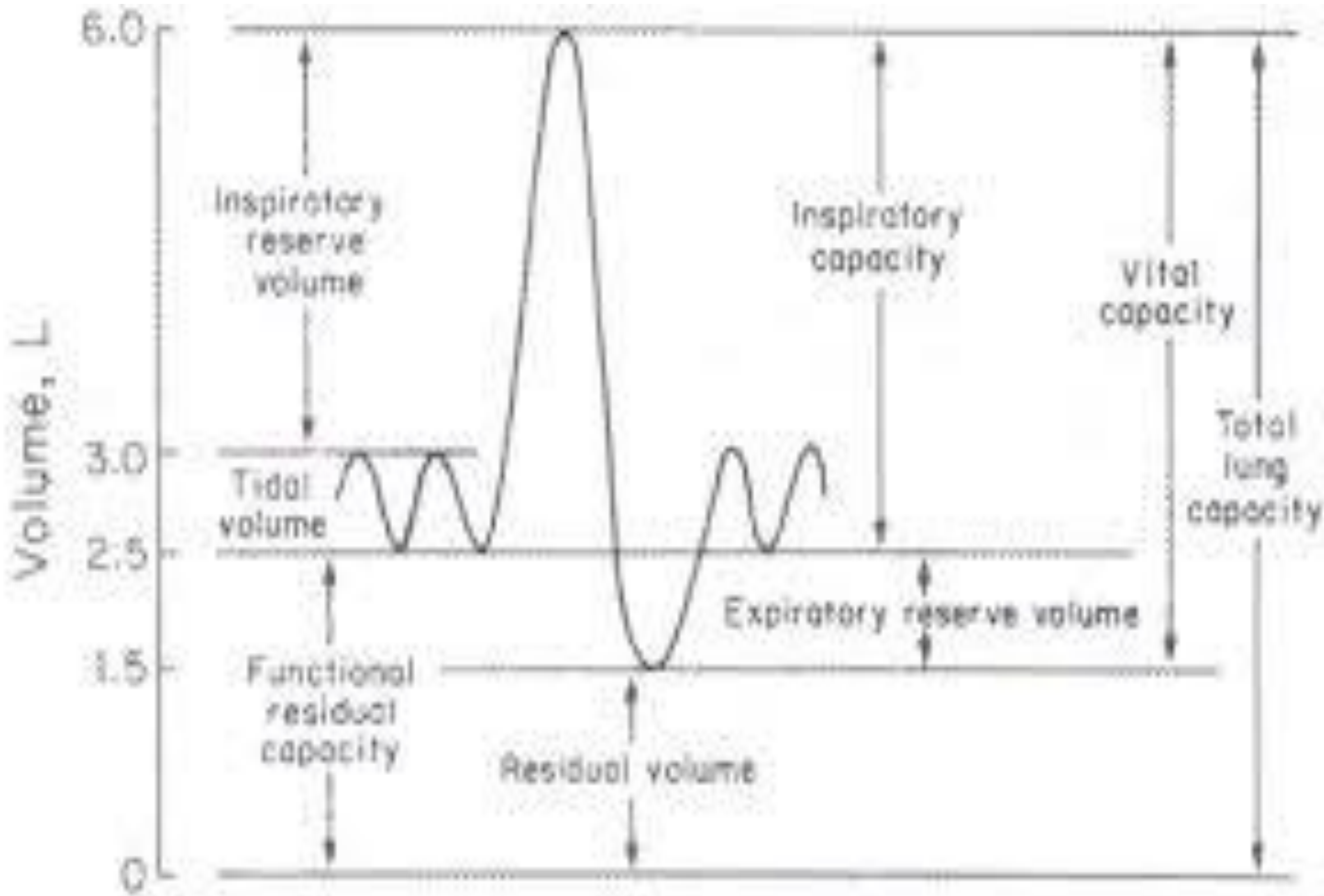
- This is the volume of air that can be expelled out by *a maximal expiration after a maximal inspiration.* It equals the *TV*+ *JRV* + *ERV* = about *4500 ml.*

- However, it *normally varies with the size of the body.* Accordingly, its measured value must be predicted relative to the body surface area.

- Normally it averages 2500 ml and 2000 ml per square meter of body surface area in young adult males and females respectively.

5. TOTAL LUNG CAPACITY

- This is the *volume of air that the lungs contain after a maximal inspiration.* It includes *all lung volumes* (TV + 1RV + ERV + RV) or, in other words, it equals the *VC* + *RV*= about *5700 ml.*


6.0
3.0
2.5
1.5
0
Volume, L
Inspiratory reserve volume
Tidal volume
Functional residual capacity
Residual volume
Inspiratory capacity
Vital capacity
Total lung capacity
Expiratory reserve volume

FACTORS THAT AFFECT THE VITAL CAPACITY (VC)

1- Posture : The VC is greater in the standing or sitting positions than in the recumbent position, *because in the latter position the lung capacity is decreased* due to 2 factors

(a) The viscera press on the diaphragm (which limits its descent).
(b) The blood volume in the lungs increases (because the venous return increases as a result of loss of the effect of gravity)

2- Movement of the diaphragm : Conditions that limit the diaphragmatic descent (e.g. *pregnancy and ascites)* decrease the VC specially in the recumbent position

3- Pulmonary blood volume : Pulmonary congestion (= increased blood volume in the lungs) e.g. *in left ventricular failure* , decreases the VC specially in the recumbent position

4- Strength of the respiratory muscles : The VC is greater in athletes than in sedentary people, and is decreased in all muscle diseases, myasthenia gravis, and diseases associated with paralysis (e.g. poliomyelitis).

5- Lung compliance (stretchability) : A decrease in the lung compliance reduces the VC. This commonly occurs in (

a) *Lung fibrosis* [e.g. after a severe TB (tuberculosis) infection].
b) *Pneumothorax* (collection of air in the pleural sac
c) *Hydrothorax* (collection of fluid in the pleural sac).

6- Lung elasticity : Reduction of the elastic property of the lungs decreases the VC e.g. in *emphysema*, in which the lungs are well inflated and their *compliance increases,* but expiration becomes difficult.

7- Resistance to air flow : An increase in the resistance to air flow reduces the VC. This occurs in *obstructive lung diseases e.g. asthma,* in which the resistance to air flow occurs mainly during expiration

8- Expansibility of the thoracic wall : A decrease in the expansion of the thorax reduces the VC. This commonly occurs due to deformities in either the thoracic cage or the vertebral column (e.g. kyphosis and scoliosis)

7- Resistance to air flow : An increase in the resistance to air flow reduces the VC. This occurs in *obstructive lung diseases e.g. asthma,* in which the resistance to air flow occurs mainly during expiration

*** The diseases that limit the lung or thoracic wall expansibility are called *restrictive lung diseases*. In these diseases, as well as in cases of pulmonary congestion and limited diaphragmatic movement *both the TLC as well as the VC are reduced.*

*** In diseases characterized by difficult expiration (e.g. emphysema and asthma), *the TLC is almost normal while the VC is decreased and the RV is increased*

*** The lung volumes already described are called *static volumes*, because they are measured while the subject is in the resting midthoracic position. All can be measured by an apparatus called the *spirometer except the residual volume*.

Therefore, the capacities that include the residual volume (i.e. FRC and TLC) *cannot be measured by this apparatus.*

Measurement of the Residual Volume

- The R V can be measured by application of the *dilution principle* as follows. The subject expires maximally (so only the RV remains in the lungs) then he breathes deeply 3 - 4 times *in a spirometer that contains a known concentration of helium in air.*

- In this way, helium is diluted by the RV and its concentration becomes equal in both the spirometer air and the RV.

- The *amount of helium remains constant during the test* because
(a) It is present in *a closed circuit*
(b) It is an *inert gas* that is not produced or utilized by the body
(c) It is almost *insoluble in the blood.*

- After equilibration, the RV is calculated as follows

1- ***The amount of helium before equilibration*** = volume of air in the spirometer (V_1) x helium concentration in that air (C_1).
2- ***The amount of helium after equilibration*** = (V_1 + RV) x final helium concentration in the spirometer air (C_2).

Since both (1) and (2) are equal (i.e. $V_1 C_1 = (V_1 + RV) C_2$), then mathematically, the **RV** = $\dfrac{V_1 (C_1 - C_2)}{C_2}$.

Clinical importance of measuring the RV

- *Normally, the RV is less than 30 % of the TLC.* Such ratio is exceeded in diseases that cause *inefficient expiration,* particularly *asthma* & *emphysema* and ratios more than 35 % indicate that the condition is serious .

Importance of the FRC and its measurement

- The FRC maintains an adequate gas exchange in the lungs in the intervals between breaths, and its large volume (about 5 times the TV) prevents acute changes in the 02 and C02 concentrations in the blood.

- It can also be measured by using the dilution principle but in this case the subject starts breathing in the spirometer after a normal expiration.

DIFFERENCES BETWEEN ALVEOLAR AND EXPIRED AIR

- The alveolar air is that air that undergoes gas exchange with blood in the pulmonary capillaries. Its volume is about *2000 ml* after a quiet expiration.

- It continuously loses O2 and gains CO2, so its O2 content is less and its CO2 *c*ontent is more than the amounts of these gases in both the inspired and the expired air

- During inspiration, the air conducting part of the respiratory passages (which is called the *anatomical dead space)* contains *atmospheric air.*

- However during the next expiration, this air is exhaled first and is followed by alveolar air (which *fills the anatomical dead s*pace *after expiration).*

- There fore, the expired air is a mixture of alveolar air and atmospheric air from the anatomical dead space.

- The following table shows the *composition of the inspired, expired and alveolar air, all fully saturated with water vapour* (PP = partial pressure in mmHg).

	CO_2		O_2		N_2 &inert gases		water vapour	
	%	PP	%	PP	%	PP	%	PP
Inspired air	0.04	0.3	19.6	149	74.16	563.7	6.2	47
Expired air	3.7	28	15.8	120	74.3	565	6.2	47
Alveolar air	5.3	40	13.1	100	75.4	573	6.2	47

** The partial pressure of O_2 in dry air is 160 mmHg

THE RESPIRATORY DEAD SPACE (DS)

- This is the space in the respiratory system *occupied by gas that does not exchange with blood.* It is subdivided into the following types :

1. Anatomical DS : This is the area in which gas exchange does not normally occur. It extends from the nose down till the respiratory bronchioles, and its volume is normally about 150 ml.

2. Alveolar DS : This includes the alveoli in which no gas exchange occurs due to blockage of their blood supply. It is normally absent(= zero).

3. Physiological DS : This is the area of *wasted ventilation* in the respiratory system (i.e. the area in which no gas exchange occurs). *It equals the sum of the anatomical and alveolar dead spaces.* Since normally no alveolar dead space exists, *the physiological DS should be normally equal to the anatomical DS.*

FUNCTIONS AND SIGNIFICANCE OF THE ANATOMICAL DS

(1) The DS constitutes *the conducting part of the respiratory tract,* which performs the following functions:
a- Conduction of air to and from the alveoli.
b- Regulation of the body temperature (by helping heat loss).
c- Control of airflow resistance (by adjusting the bronchial tone).
d- Providing *several protective mechanisms.*

❑ The protective mechanisms are:
- Conditioning of the inspired air.
- Filtration of the inspired air from harmful foreign particles.
- Elimination of the foreign particles by the ciliary escalator.
- Formation of immunoglobulins (antibodies).
- Initiation of the sneeze and cough reflexes.

(2) The nasal olfactory mucosa perceives *the sensation of smell.*
(3) The larynx is concerned with *phonation* (sound production).
(4) The anatomical DS is the cause of the *difference between the total and effective ventilation,* and is used as *a pulmonary function test*

ASSESSMENT OF PULMONARY FUNCTION

❑The efficiency of the respiratory system can be assessed by determining one or more of the following parameters :

I . The pulmonary ventilation.
2. The dead space : The presence of non-functioning alveoli is indicated by a greater physiological DS than the anatomical DS.
3. The lung compliance.
4. The ventilation perfusion ratio.
5. The static lung volumes and capacities.

6. The timed vital capacity.
7. The maximal breathing capacity and the breathing reserve
8. The peak expiratory flow.
9. The levels of both O_2 and CO_2 in the blood (in cases or severe pulmonary insufficiency. the blood *O_2* level decreases while the blood C02 level increa5es and is associated with acidosis)

PUL MONARY VENTILATION (PV)

- The term PV means *lung aeration with atmospheric air,* and it is tested by measuring one or both of the following volumes

(1) The total PV or respiratory minute volume (RMV)

- This is the total volume of air that is inspired per minute It is calculated by multiplying the (TV) x breathing rate per minute Since normally the former is about 500 ml and the latter about 12 per minute, then the normal
total PV (or RMV) = 500 x I2 = 6000 ml (6 litres) per minute

(2) The alveolar PV (or effective PV)

- This is *the volume of air that actually ventilates the alveoli per minute* Since about 150 ml of the inspired TV normally remain in the anatomical dead space, then *during rest* only *about 350 ml of* the *TV reach the alveoli each breath* and the resting alveolar ventilation = 350 x 12 =*4200 ml (4. 2 litres) per minute.*

- The alveolar PV is more significant than the total PV. It is frequently altered in disease while the total PV remains constant e.g. :

1- In a case of *tachypnea* (rapid shallow breathing due to any cause), if the breathing rate increases to 30 / minute, the TV may decrease down to 200 ml, and in this case. the total PV remains constant at 6000 ml (200 x 30) while the alveolar PV is markedly decreased, becoming only I500 ml (200-150 X 30).

2- In a case of slow deep breathing due to any cause. if the breathing rate decreases to 6 / minute, the TV may increase up to I000 ml and in this case, the to al PV remains constant at 6000 ml (I000 x 6) while the alveolar PV is markedly increased, becoming 5100 ml (I 000- 150 x 6).