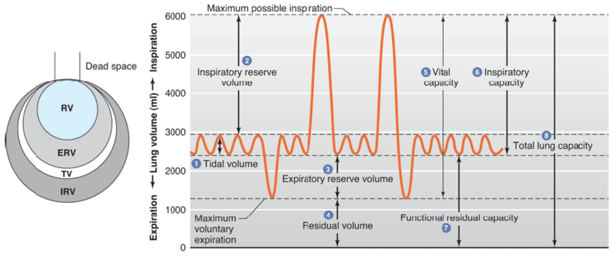
PULMONARY GAS VOLUMES AND VENTILATION



Respiratory Volumes and Capacities for an Average Young Adult Male

Measurement	Typical Value	Definition
Respiratory Volumes		
1 Tidal volume (TV)	500 ml	Amount of air inhaled or exhaled in one breath during relaxed, quiet breathing
2 Inspiratory reserve volume (IRV)	3000 ml	Amount of air in excess of tidal inspiration that can be inhaled with maximum effort
3 Expiratory reserve volume (ERV)	1200 ml	Amount of air in excess of tidal expiration that can be exhaled with maximum effort
4 Residual volume (RV)	1200 ml	Amount of air remaining in the lungs after maximum expiration; keeps alveoli inflated between breaths and mixes with fresh air on next inspiration
Respiratory Capacities		
5 Vital capacity (VC)	4700 ml	Amount of air that can be exhaled with maximum effort after maximum inspiration (ERV + TV + IRV); used to assess strength of thoracic muscles as well as pulmonary function
6 Inspiratory capacity (IC)	3500 ml	Maximum amount of air that can be inhaled after a normal tidal expiration (TV + IRV)
7 Functional residual capacity (FRC)	2400 ml	Amount of air remaining in the lungs after a normal tidal expiration (RV + ERV)
8 Total lung capacity (TLC)	5900 ml	Maximum amount of air the lungs can contain (RV + VC)

Pulmonary Volumes

To the left in are listed four pulmonary lung volumes that, when added together, equal the maximum volume to which the lungs can be expanded. The significance of each of these volumes is the following: The tidal volume is the volume of air inspired or expired with each normal breath; it amounts to about 500 milliliters in the adult male. The inspiratory reserve volume is the extra volume of air that can be inspired over and above the normal tidal volume when the person inspires with full force; it is usually equal to about 3000 milliliters. The expiratory reserve volume is the maximum extra volume of air that can be expired by forceful expiration after the end of a normal tidal expiration; this normally amounts to about 1200 milliliters. The residual volume is the volume of air remaining in the lungs after the most forceful expiration; this volume averages about 1200 milliliters.

Pulmonary Capacities

In describing events in the pulmonary cycle, it is sometimes desirable to consider two or more of the volumes together. Such combinations are called pulmonary capacities.To the right are listed the important pulmonary capacities, which can be described as follows: The vital capacity equals the inspiratory reserve volume plus the tidal volume plus the expiratory reserve volume. This is the maximum amount of air a person can expel from the lungs after first filling the lungs to their maximum extent and then expiring to the maximum extent (about 4700 milliliters). The inspiratory capacity equals the tidal volume plus the inspiratory reserve volume. This is the amount of air (about 3500 milliliters) a person can breathe in, beginning at the normal expiratory level and distending the lungs to the maximum amount. The functional residual capacity equals the expiratory reserve volume plus the residual volume. This is the amount of air that remains in the lungs at the end of normal expiration (about 2400 milliliters). The total lung capacity is the maximum volume to which the lungs can be expanded with the greatest possible effort (about 5900 milliliters); it is equal to the vital capacity plus the residual volume.

As discussed in the previous page, the FRC has particular importance with realtion to the closing capacity. A range of different factors affect the FRC. These include sex; for the same body height, females have a FRC that is 10% less than males. Age; FRC increases slightly with age increasing about 16ml per year. Body size; FRC is linearly related to height. Obesity causes a marked reduction in FRC compared to lean subjects of the same height. These factors may be combined to calculate FRC for example in white males aged 25-65 FRC = (5.95 X metre height) + (0.019 X age) - (0.086 X BMI) - 5.3. Other factors which influence the FRC are diaphragmatic muscle tone and posture. The later is may result in differences of between 500-1000ml between the supine and upright positions. This is caused by the pressure of the abdominal contents on the diaphram. Finally lung disease plays a major role in variation of FRC. Anything that increases the elastic recoil of the lungs, thoracic cage or both will decrease FRC. Possible causes include lung fibrosis, pleural thickening, kyphoscoliosis, obesity and scarring of the thorax such as in a burns patient. Conversely, if the elastic recoil of the lungs is diminished such as in emphysema and asthma the FRC is usually increased. This is beneficial as the airway resistance is decreased as the lung volume increases.

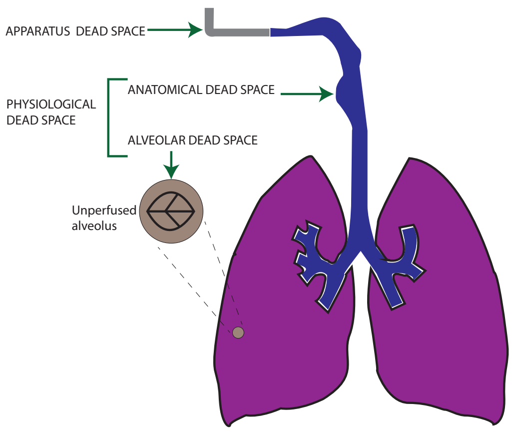
Measurement of respiratory volumes

Most of the volumes and capacities may be measured or inferred using normal spirometry. The residual volume however in not able to be calculated by this method, and therefore also the functional residual capacity and total lung capacity. Three methods may be employed to calculate these unknowns. The first employs nitrogen washout by breathing 100% oxygen. If the lungs are initially at 80% N2 (before the 100% O2) and 4 Litres is collected following complete washout with O2, then the total lung capacity can be calculated as 5 Litres. The second method is a wash in of a tracer gas. If 50ml of Helium is inhaled and the helium concentration is then found to be 1%, TLC is calculated as 5 Litres. The third method involves a body plethysmograph, the pressures and volumes are measured and boyles law is applied.

Dead space

It was realised in the 19th century that a component of each inspiration that does not penetrate the regions of the lung in which gas exchange took place and therefore was exhaled unchanged. This fraction of the tidal volume is known as the dead space whilst the efective component of the minute volume of respiration is known as the alveolar ventilation.

$$\boxed{\text{Alveolar Ventilation} = \text{Respiratory Frequency (tidal volume - dead space)}}$$



The first component to dead space is the apparatus dead space which is only a factor if there is external breathing apparatus such as a ventilator.

The next component is the anatomical dead space. This consists of the volume of all the conducting airways where gas exchange does not take place. In normal physiological settings it is approximately 2ml/kg, and often simplified to 150ml in adults (equivalent to a 75kg individual). Despite this simplification it is important to be aware of the circumstances where it may be variable beyond the patient weight. In neonates and infants the ADS is increased due to the disproportionate size of the head and neck, and a value of 3.3ml/kg is used up to the age of 6. Posture is important with a supine patient having approximately 30% less ADS. The position of the neck and jaw is also significant with sniffing the roses producing higher volumes and neck flexed and chin depressed decreasing the volume. Increasing FRC results in a larger ADS. Drugs which affect bronchiolar tone influence ADS. Finally tracheal intubation, tracheostomy or LMAs bypass much of the extrathoracic ADS which is normal about 70ml.

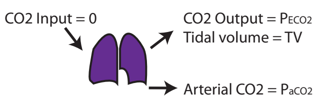
The alveolar dead space is the part of the inspired gas that passes through the ADS but does not take part in gas exchange. The cause of the failure of gas exchange is lack of effective perfusion of the spaces to which gas is distributed at the alveolar level. The alveolar dead space is too small to be measured with confidence in healthy subjects but may be significant in two pathological states. Pulmonary embolism is a direct cause of alveolar dead space that may reach massive proportions. Low cardiac output results in decreased pulmonary perfusion to the uppermost parts of the lung, and has appreciable influence on the alveolar dead space.

Physiological dead space

is is the sum of all the parts of the tidal volume that do not take place in gas exchange. It is calculated by the Bohr equation and represents the sum of the ADS and alveolar dead space.

Bohr equation

Uses three parameter to estimate the physiological dead space and is based on the assumption that only perfectly perfused and ventilated alveoli take place in exchange (and therefore the CO_2 equalises vessel-alveolus) and the inspired CO_2 is 0. The three parameters are Tidal Volume, End tidal CO2 and Arterial PCO2.



$$\boxed{P_{ECO_2} \times TV = P_{aCO_2} \times (TV - PDS)}$$

normally: $TV = 500$

$P_{ECO_2} = 28$

$P_{aCO_2} = 40$

$28(500) = 40\,(500\text{-}PDS)$

therefore; $PDS = 150$

Fowler method

This orginially used a nitrogen washout technique, but has been subsequently modified to a CO2 washout technique. It is based on a graphical method shown adjacent.