Lung volumes

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LUNG VOLUMES

a. primary lung volumes

i. RV Residual Volume
ii. ERV Expiratory Reserve Volume
iii. TV Tidal Volume
iv. IRV Inspiratory Reserve Volume

b. secondary derived capacities

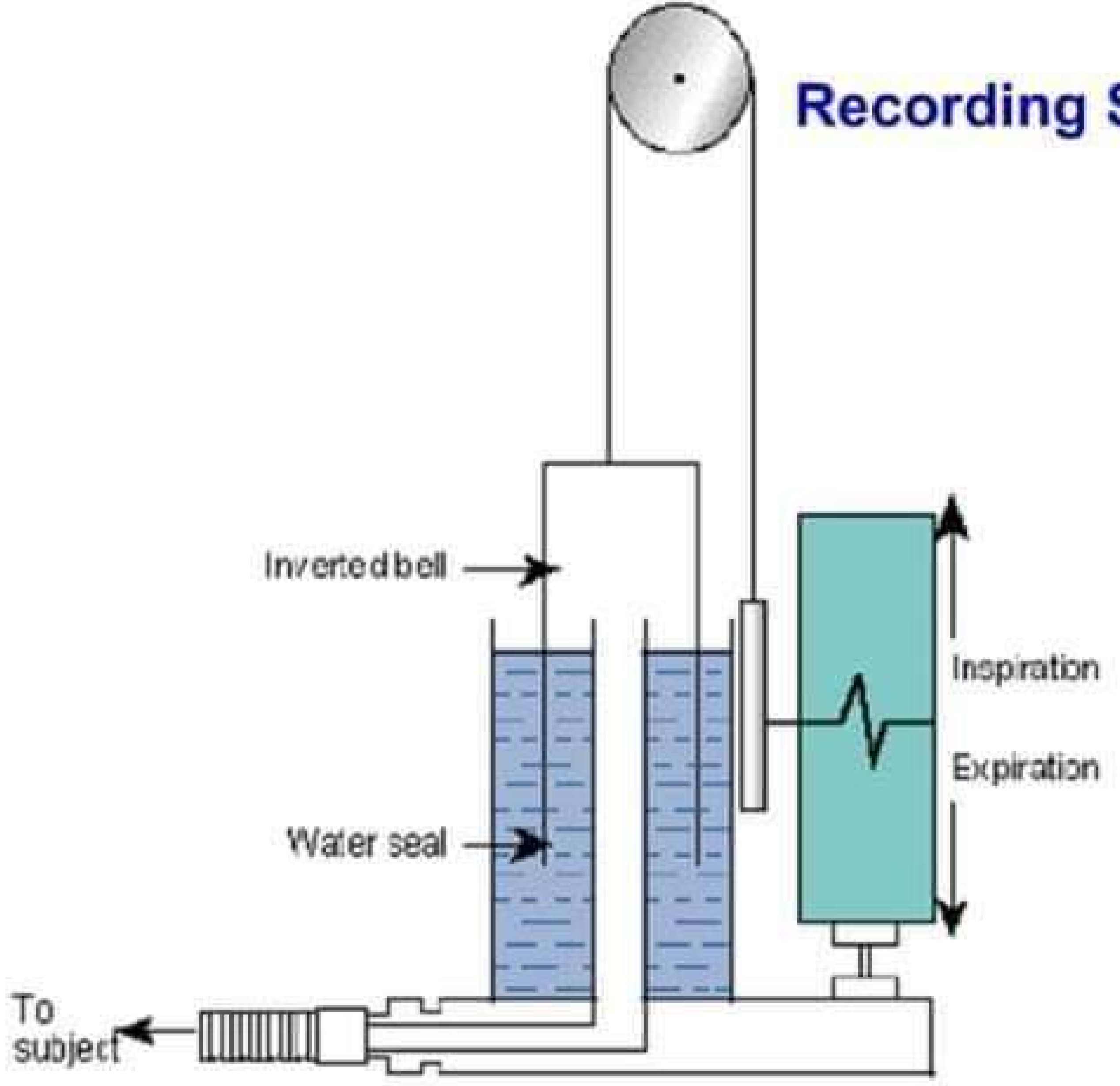
i. TLC Total Lung Capacity
ii. VC Vital Capacity
iii. IC Inspiratory Capacity
iv. FRC Functional Residual Capacity

Definitions:

- **Volume** refers to one of the 4 primary, non-overlapping subdivisions of TLC.

- Each **capacity** includes two or more of the primary lung volumes.

Recording Spirometer



Measurement of lung volumes:

Lung volumes are measured by spirometry.

A spirometer consists of a counterbalanced bell, which is connected to a pen writing on a rotating drum.

The air-filled bell is inverted over a chamber of water, so an airtight chamber is formed.

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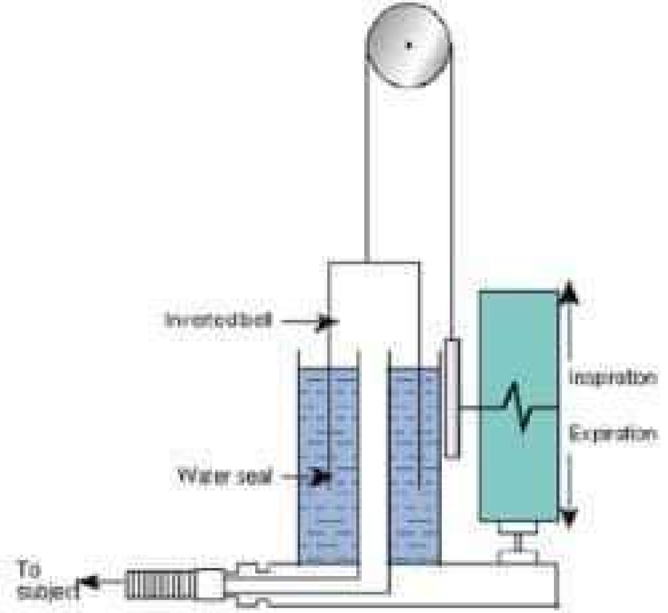


The bell is counterbalanced so it moves up and down with respiration with minimal resistance.

Volume changes can be recorded on volume and time calibrated paper.

Lung volumes measured with the spirometer:

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).

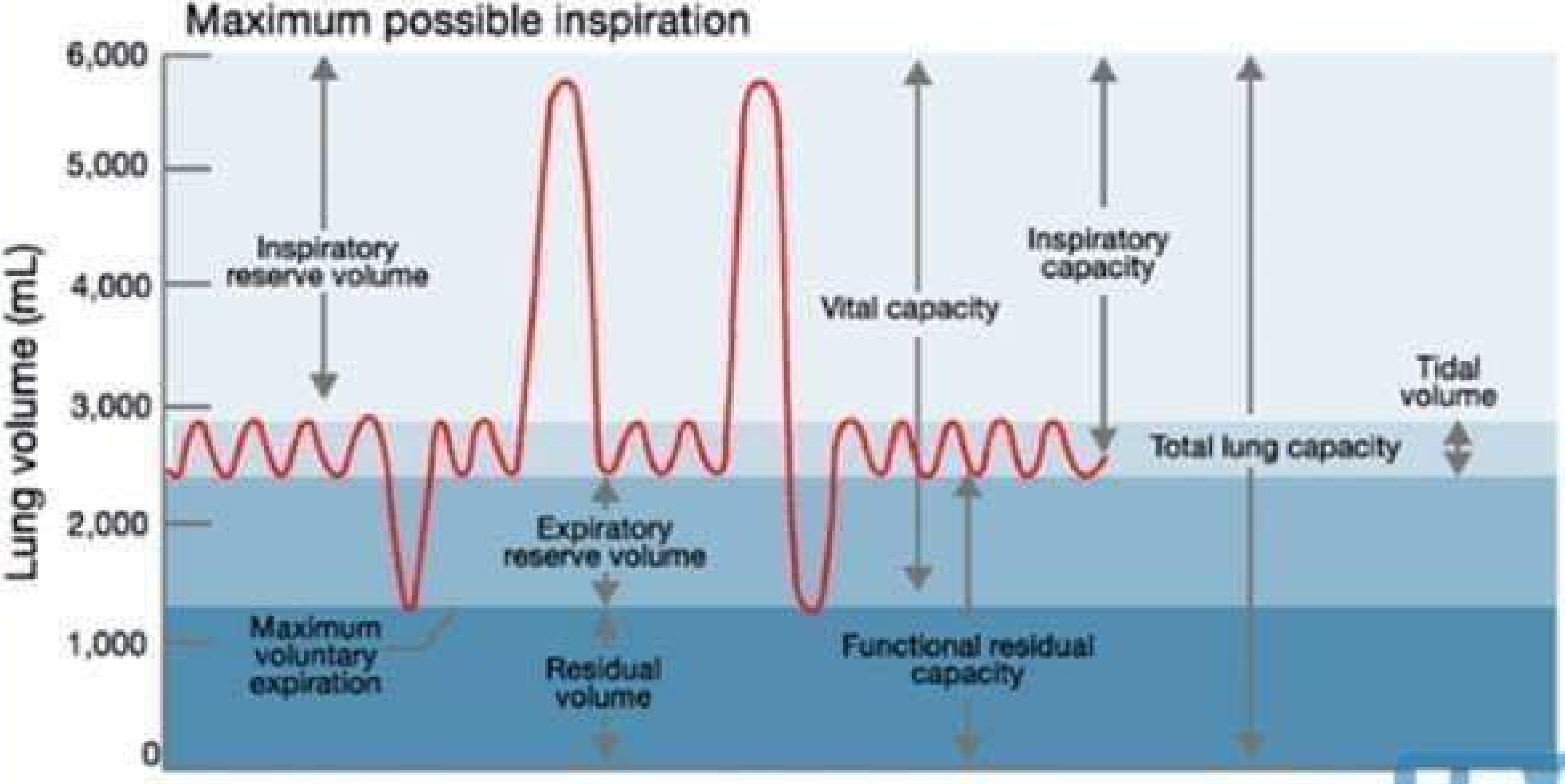
Capacities calculated from volumes:

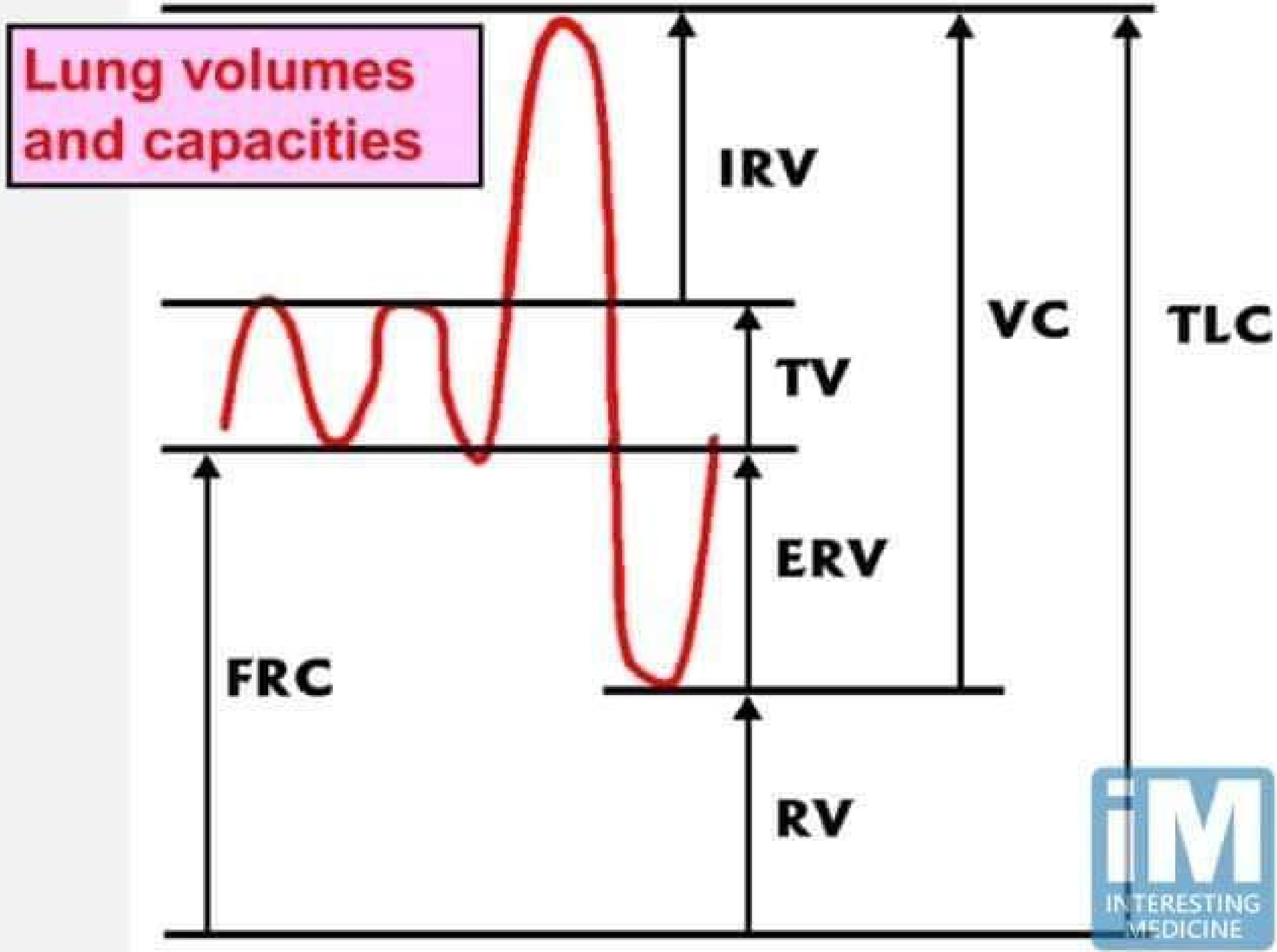
Inspiratory capacity (IC): Maximal volume of air inhaled after a normal expiration (3.6 L) (TV+IRV).

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)

Lung Volumes and Capacities




Lung volumes
and capacities
IRV
TV
ERV
RV
FRC
VC
TLC
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FRC and RV can not be measured with an ordinary spirometer as lungs cannot be emptied fully.

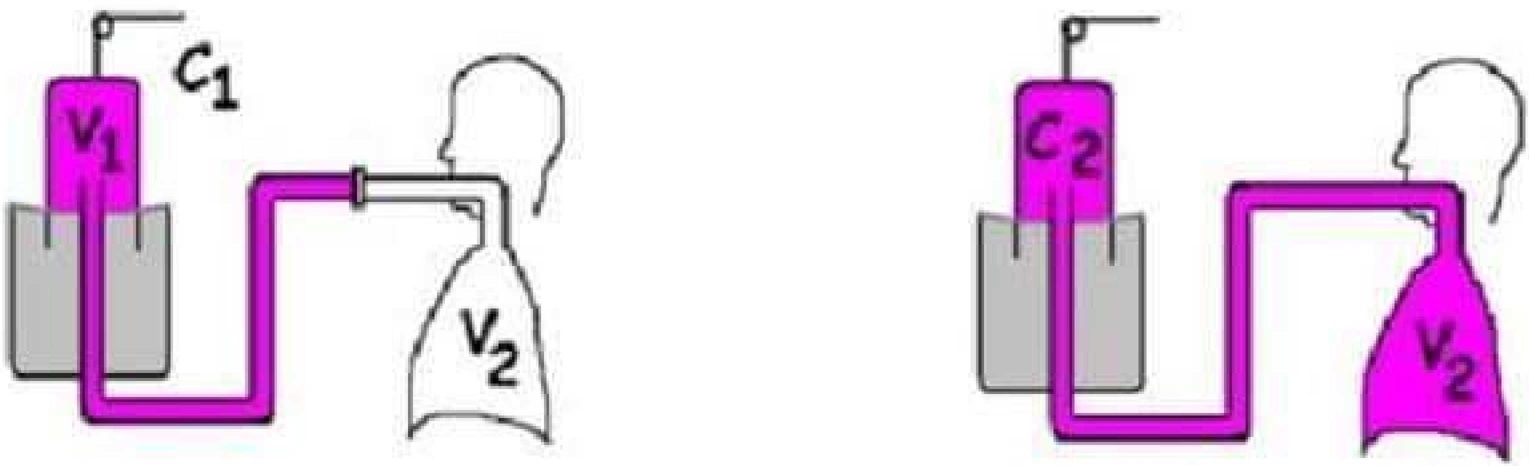
Methods of measurement:

1. Closed circuit helium dilution

2. Closed circuit nitrogen washout

3. Body plethysmograph

Helium Dilution Spirometry:



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1. Closed Circuit Helium Dilution Spirometry:

Rebreathing takes place from a spirometer of known volume ($V1$) and helium concentration ($C1$).

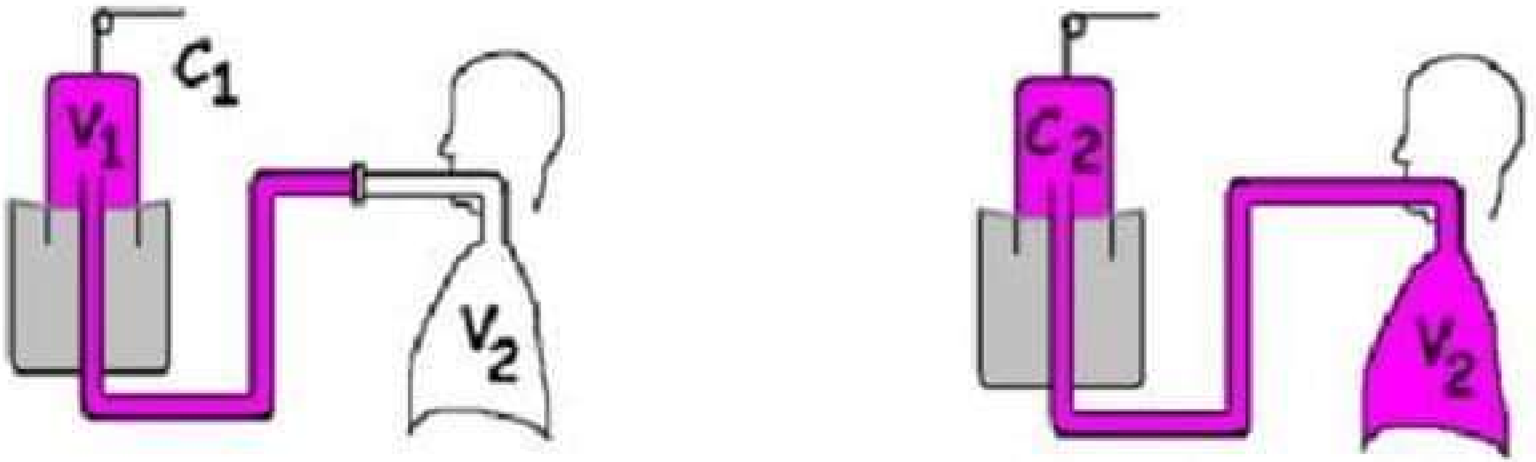
As He is relatively insoluble in blood, it therefore equilibrates between the lung and spirometer.

Volumes are calculated by conservation of mass, ie. $C1 \times V1 = C2 \times (V1+V2)$, depending upon the starting point,

i. from end tidal expiration □ FRC

ii. from end forced expiration □ RV

Helium Spirometry:



$$V1 x\ C1 = C2\ x\ (V1 + V2)$$
$$V2 = V1\ x\ (C1 - C2)\ /\ C2$$
$$V2 = FRC$$

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2. Closed Circuit Nitrogen Dilution:

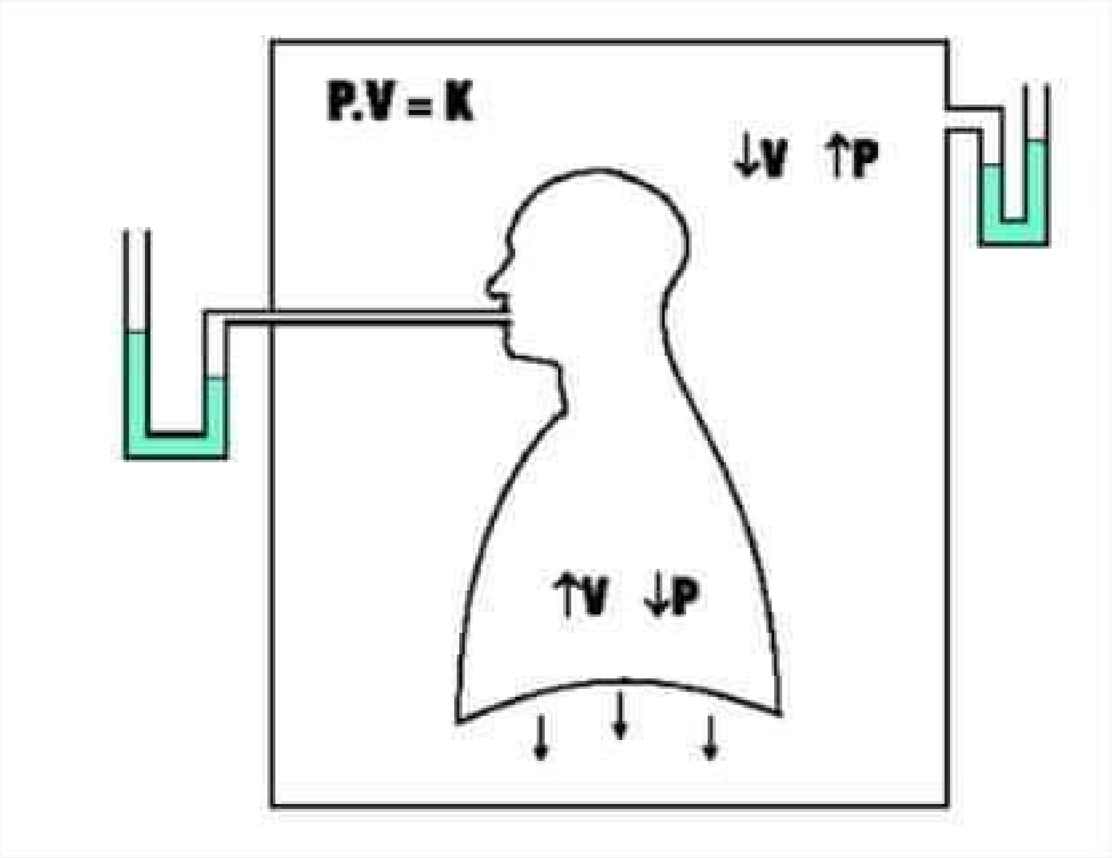
Using N2 washout technique, the patient breaths 100% O_2.

If the alveolar N_2 = 80% and the volume of N_2 collected is 4.0 L, then the initial lung volume must have been 5.0 L.

Relies upon N_2 being relatively insoluble and moving slowly from blood to alveolar air.

3. 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.



Body plethysmograph:

When the subject makes an inspiratory effort against a closed airway he

- slightly increases the volume of his lung,
- airway pressure decreases and
- the box pressure increases:

Calculation:

$$P_1V_1 = P_2(V_1 - \Delta V) \text{ where,}$$

P_1= Pressure in the box before and

P_2 = after the respiratory efforts

V_1 = Volume in box before respiratory efforts

Thus, ΔV (change in volume of the box or lung) can be measured.

Calculation - contd:

Now we apply Boyle's law to the gas in the lung:

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

P_3 = Mouth pressures before and
P_4 = after the respiratory efforts.
ΔV is known from previous equation.
Thus, V_2 can be calculated and then

$V_2 = FRC$

If the measurement is done following a forced expiration, then

$V_2 = RV$

Functional Residual Capacity:

Definition: the volume of gas left in the lungs at the end of normal tidal expiration.

FRC is the lung volume in which gas exchange is taking place.

Small fluctuations of alveolar and arterial gas tensions occur with each tidal breath as fresh gas mixes with alveolar air.

FRC therefore acts as a buffer,

1. maintaining relatively constant A & a gas tensions with each breath.
2. preventing rapid changes in alveolar gas with changes in ventilation or inspired gas.

Factors Affecting Lung volumes:

1. **Body size** - All volumes are larger in larger people.
2. **Sex** - All volumes are slightly smaller in females; not merely due to differences in body size.
3. **Age** - Volumes are smaller in children. In old age, degenerative changes cause the VC to decrease and RV to increase.
4. **Ethnicity** - Lung volumes differ in ethnic groups with Europeans having the largest lung volumes and Polynesians having smaller lung volumes than Europeans.
5. **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 x 15 = 7500 ml/min.

It can be measured by having the subject breathe through a valve that separates the inspired air from expired air and collecting the expired air.

Alveolar ventilation:

Definition: 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 to diffusion (*Anatomic dead space*).

Thus, the volume of gas entering the respiratory zone, **alveolar ventilation**, is (500-150) x 15 = 5250 ml/min.

Anatomical dead space:

Definition: The volume of the conducting airways in which no gas exchange takes place,

Also termed the series dead space and is equal to the boundary between convective gas transport and diffusion.

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Alveolar Dead Space:

Definition: that part of the inspired gas which passes through the anatomical dead space and enters alveoli, but is ineffective in arterialising mixed venous blood.

Also termed **parallel dead space.**

Alveolar Dead Space - contd:

The alveolar dead space does not represent the actual volume of the non-perfused alveoli.

The cause is failure of adequate perfusion of the alveoli to which gas is distributed due to:

a. alveoli with no perfusion□ V/Q infinite
b. alveoli with reduced perfusion □ V/Q > 0.8

The separation of alveoli into these two groups is normally is minimal in healthy subjects but increases with disease.

Physiological Dead Space

Definition: V_D^{Phys} = Total Dead Space

$= V_D^{Alv} + V_D^{Anat}$

or - That part of the tidal volume which does not participate in gas exchange and is ineffective in arterialising mixed venous blood, because either,

1. it doesn't reach the alveoli - V_D^{Anat}
2. it reaches alveoli with no capillary flow, or
3. it reaches alveoli with inadequate flow - V_D^{Alv}

in normal supine man, $V_D^{Alv} \sim 0$, therefore,

$V_D^{Phys} = V_D^{Anat} = 150$ ml

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