Respiratory module

Session 2:

Lecture 2: Gas exchange and Ventilation of the lungs

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Objectives

describe the properties of the mechanical system comprising the lungs, chest wall and diaphragm

define the terms 'Functional Residual Capacity', 'Residual Volume', 'Vital Capacity' and 'Inspiratory Capacity‘

define the terms 'Serial dead space' and 'Physiological dead space' and state in general terms how these variables are measured

calculate alveolar ventilation rate when given the pulmonary ventilation rate, dead space volume and respiratory rate

Objective 1

describe the properties of the mechanical system comprising the lungs, chest wall and diaphragm

The partial pressure of inspired air is further changed by **gas exchange** occurring in the alveoli.

The blood flowing through the alveolar capillaries picks up O_2 and loses CO_2 by diffusion of these gases across the alveolar wall.

At the same time there is diffusion of O_2 & CO_2 between alveolar gas and fresh atmospheric air in the terminal and respiratory bronchioles brought in by ventilation.

Alveolar pO_2 balance

Alveolar pCO_2 balance

The balance between perfusion and ventilation, keeps the partial pressure of

oxygen and carbon dioxide in the **alveolar gas** stable at its normal values of 13.3 kPa and 5.3 kPa respectively

Blood flowing through the alveolar capillaries picks up oxygen and loses carbon dioxide by diffusion of those gases across the alveolar wall.

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The rate at which gases exchange is determined by three factors:

Area available for exchange

Resistance to diffusion

Gradient of partial pressure

The area of the alveolar surfaces is large because there are a huge number of alveoli, generating in a normal lung an exchange area of around **80 m^2**. In normal lungs, therefore the area available is not a limiting factor on gas exchange.

The diffusion pathway from alveolar gas to alveolar capillary blood is short, but there are several structures between the two. First gas must diffuse through the gas in the alveoli, then through:

The alveolar epithelial cell

Interstitial fluid

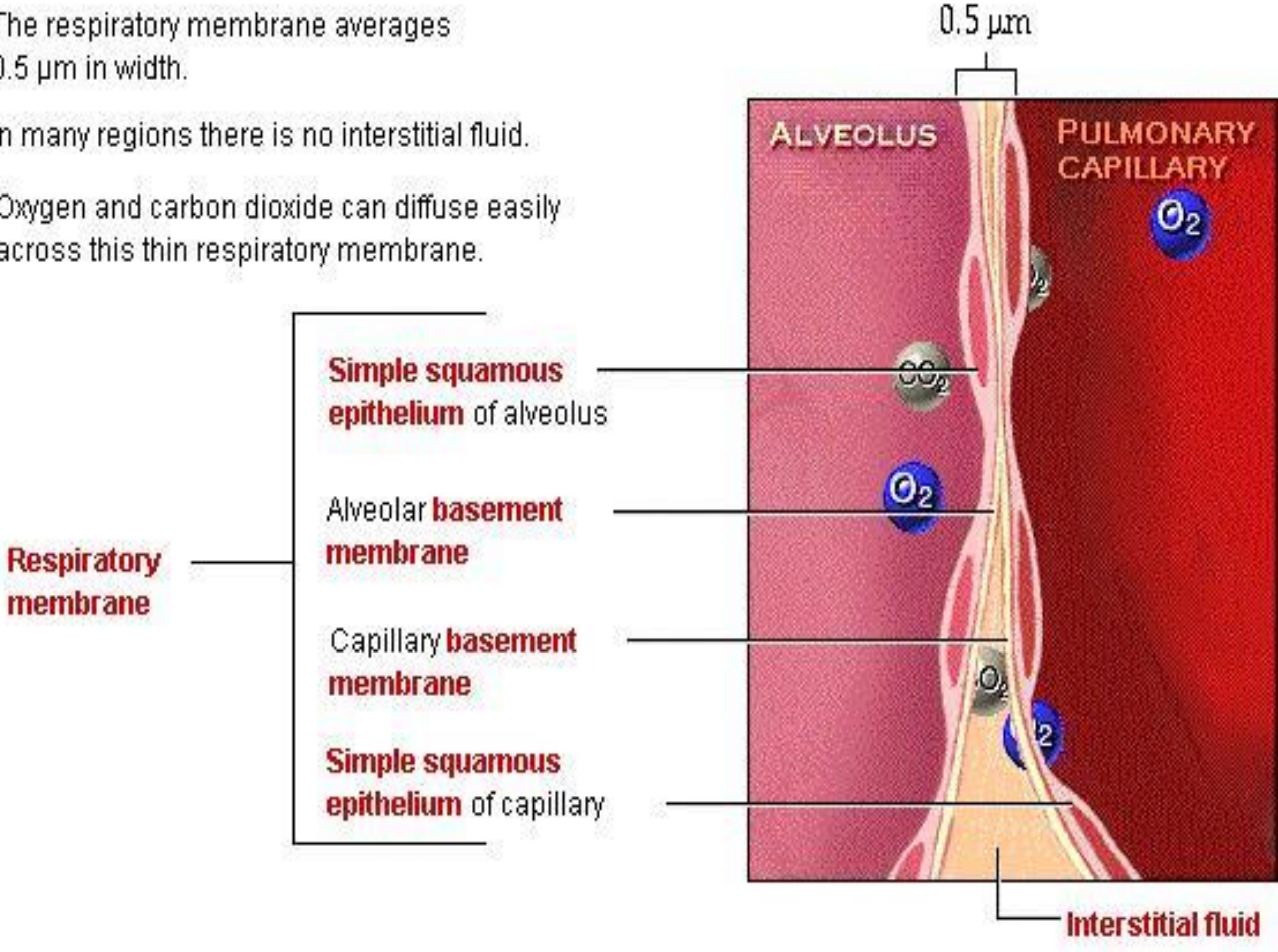
Capillary endothelial cell

Plasma

The respiratory membrane averages 0.5 µm in width.

In many regions there is no interstitial fluid.

Oxygen and carbon dioxide can diffuse easily across this thin respiratory membrane.



Two gases have to diffuse, oxygen into blood and carbon dioxide out of it. The resistance is not the same for the two gases. For most of the barrier (the cells, membranes and fluid) the rate of diffusion is affected by the solubility of the gas in water, and carbon dioxide diffuses much faster, because it is more soluble.

Overall, carbon dioxide diffuses 21 times as fast as oxygen for a given gradient. This means that anything affecting diffusion will only change oxygen transport, as that is limiting.

The rate of exchange of oxygen is normally very rapid, so that within half a second of blood arriving in the alveolar capillary it has equilibrated with the gas in the alveoli. This means that: In a normal subject, the partial pressures of oxygen and carbon dioxide in arterial blood will be the same as the partial pressures in the alveolar gas.

The partial pressure of oxygen and carbon dioxide in the alveolar gas must therefore be kept very close to their normal values of 13.3 kPa and 5.3 kPa respectively if the tissues of the body are to be properly supplied with oxygen and lose their carbon dioxide. This is achieved by exchange of gas between alveolar gas and atmospheric air brought close to it through the airways of the lung by the process of **ventilation**.

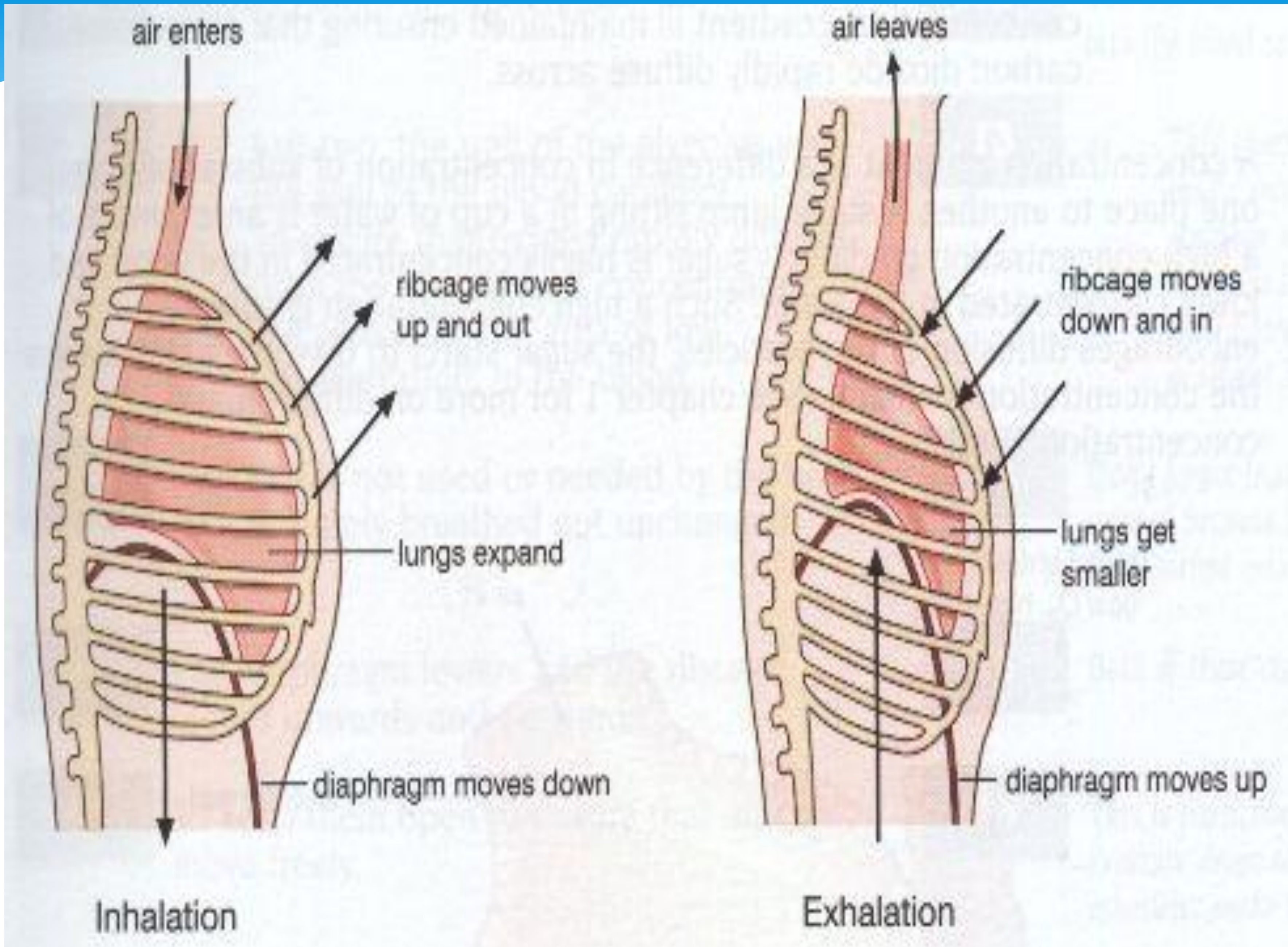
There are no valves in the respiratory system **-** movement of air is **tidal**.

The movement of air during breathing can be measured by **Spirometry.**

Ventilation:

Air is driven through the airways of the lungs by pressure changes produced by increases and decreases in the volume of the air spaces next to the alveoli. The movements of breathing lower pressure in the terminal and respiratory bronchioles during inspiration, so air flows down the airways to them, and then increase pressure during expiration so air flows back out again.

Fresh atmospheric air does not enter the alveoli, and exchange of oxygen and carbon dioxide occurs by diffusion between alveolar gas and atmospheric air in the terminal and respiratory bronchioles.


air enters
ribcage moves
up and out
lungs expand
diaphragm moves down
Inhalation
air leaves
ribcage moves
down and in
lungs get
smaller
diaphragm moves up
Exhalation

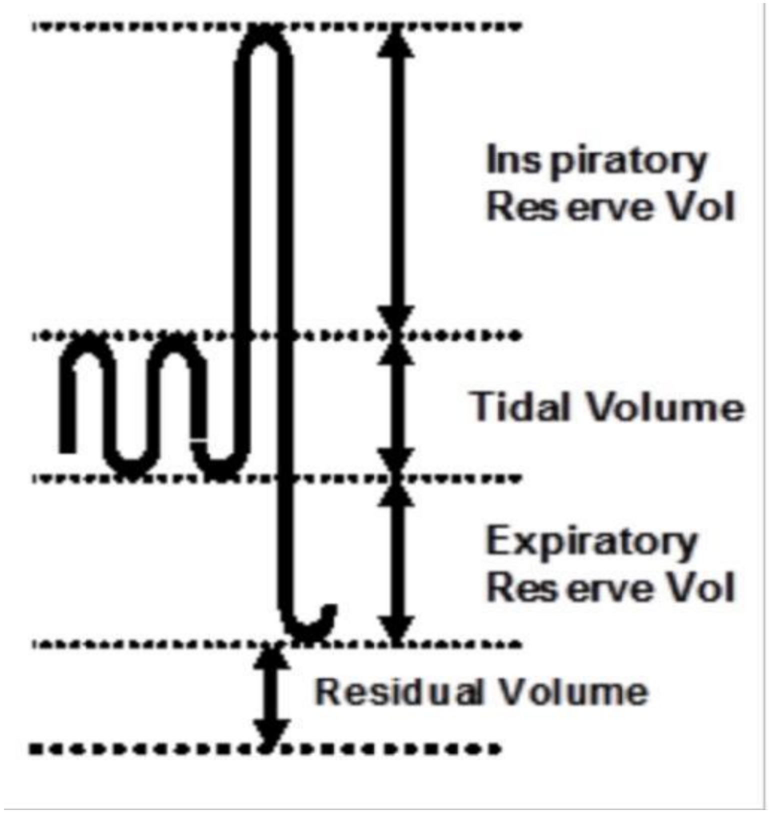
Lung Anatomy.mp4

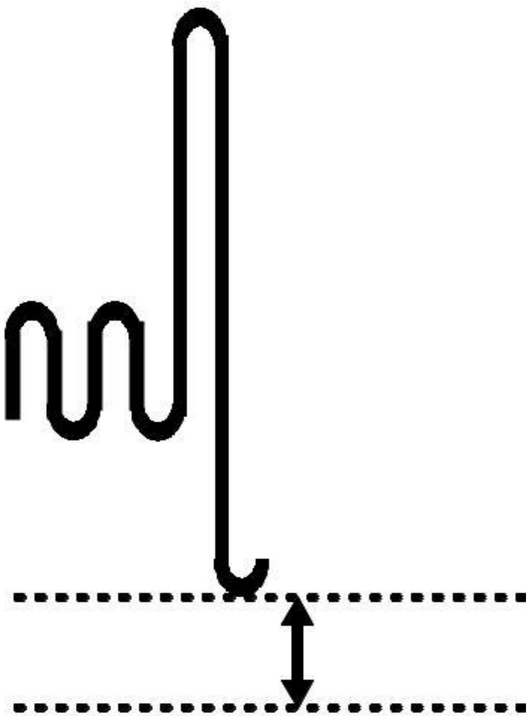
Objective 2

define the terms 'Functional Residual Capacity', 'Residual Volume', 'Vital Capacity' and 'Inspiratory Capacity

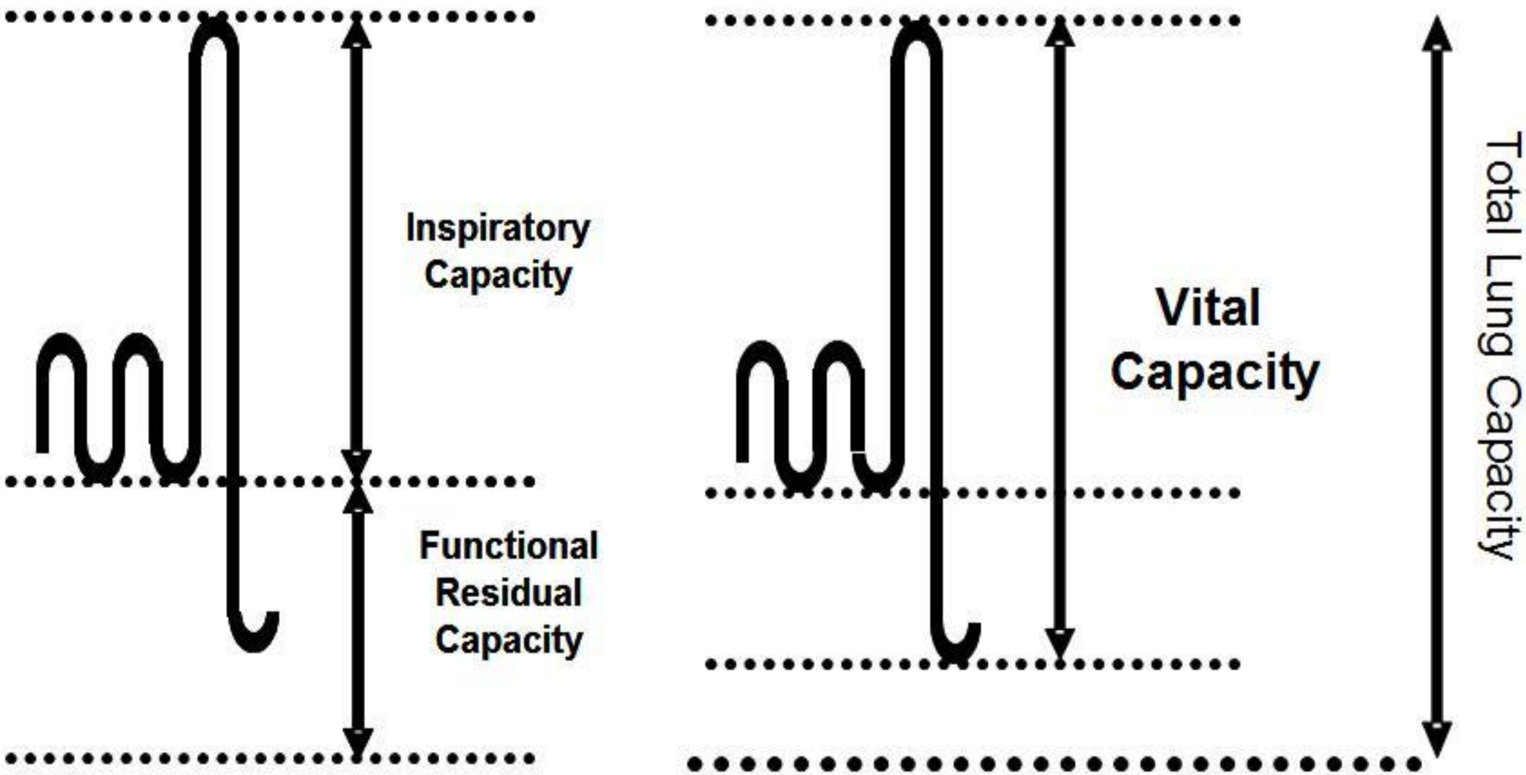
A certain volume enters and leaves the lungs with each breath - **The Tidal Volume.**

During normal respiration the increase in lung volume is not maximal - it can be increased to the extent of the **Inspiratory Reserve Volume.** We can also breathe out more than at rest, by using the **Expiratory Reserve Volume**.


Inspiratory
Reserve Vol
Tidal Volume
Expiratory
Reserve Vol
Residual Volume



We cannot however empty our lungs completely, so even after a forced expiration a **residual volume** will remain. Lung volumes change with changes in tidal volume. Lung capacities do not change with tidal volume, as they are defined relative to fixed points in the breathing cycle. These are maximum inspiration, maximum expiration, and the end of a quiet expiration.


Inspiratory
Capacity
Functional
Residual
Capacity
Vital
Capacity
Total Lung Capacity

Inspiratory capacity is from end of quiet expiration to maximum inspiration. (ie inspiratory reserve + tidal volumes)

Functional residual capacity is the volume of air in the lungs at the end of a quiet expiration

Vital Capacity = Inspiratory capacity + Expiratory Reserve

OR

Inspiratory reserve volume + TV + Expiratory reserve volume

Total lung volume = Vital Capacity + Reserve Volume

For a typical adult

	Male	Female
Tidal Volume	0.5 l	0.5 l.
Inspiratory reserve volume	3.3 l	2.2 l
Expiratory reserve volume	1.2 l	1.0 l
Residual Volume	0.8 l	0.7 l
Functional residual capacity	2.0 l	1.7 l
Inspiratory Capacity	3.8 l	2.7 l
Vital Capacity	5.0 l	3.7 l
Total Lung Volume	5.8 l	4.4 l

Dead Space

The air moved in the tidal volume, enters both the conducting pathways and the terminal and respiratory bronchioles.

Only part of the inspired air is therefore available for gas exchange - the remainder is contained in Dead Space and undergoes no interaction with the blood. The volume of the conducting airways (up to and including the terminal bronchiole) is known as the **Anatomical dead space (or Serial Dead Space)**, and is normally about 150mL. This may be measured by the **nitrogen washout test.**

Objective 3

define the terms 'Serial dead space' and 'Physiological dead space'

and state in general terms how these variables are measured

The air contained in the conducting airways is not the only air which fails to equilibrate with alveolar capillary blood. Some alveoli receive an insufficient blood supply; others are damaged by accident or disease, so that even in the air which reaches the alveolar boundary, there is a certain proportion which fails to exchange. The volume of air in alveoli not taking part in gas exchange is known as the **Alveolar dead space (or distributive dead space)**

Objective 4

calculate alveolar ventilation rate when given the pulmonary ventilation rate, dead space volume and respiratory rate

The sum of the **Anatomical dead space** **+** **Alveolar dead space** is known as the **Physiological Dead Space.** The physiological dead space can be determined by measuring pCO_2 (or pO_2) of expired and alveolar air. Alveolar air is diluted by dead space air to form the expired air, and the degree of dilution is a measurement of the physiological dead space.the dead space is affected by certain factors.

The total rate of movement of air into and out of the lungs - the **Pulmonary Ventilation Rate,** is therefore composed of two components - movement of air into and out of the dead space **- Dead Space Ventilation** - which has no effect upon the blood, and **Alveolar Ventilation.**

Alveolar Ventilation Rate

At each breath the dead space is fully ventilated. The deeper the breath the higher the proportion of air available for gas exchange. All other things being equal, deeper breathing is more effective breathing. In practice the ideal depth of respiration is limited by mechanical factors