Paediatric Critical Care

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RESPIRATORY PHYSIOLOGY : PART I

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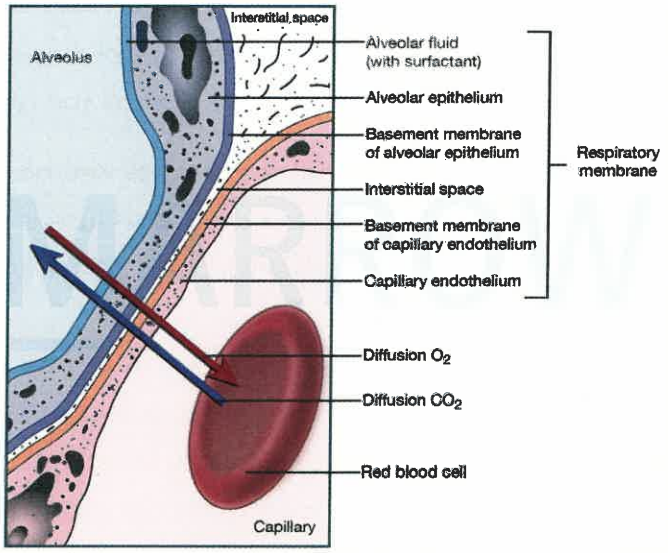
Physiology of gas exchange

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Diffusion of pulmonary gases :

Alveolar capillary(AC) membrane is made up of alveolar epithelium, interstitial space, basement membrane, capillary endothelium and red blood cell.

- Ventilation merely moves gas into and out of the lungs.
- The process that moves gas across the A-C membrane is passive diffusion.
- Diffusion is the movement of gas molecules from an area of high concentration to an area of low concentration.



Alveolar capillary membrane

Atmospheric gas :

- Barometric pressure is the sum of all gases exerting pressure on the earth's surface.
- At sea level atmospheric pressure is 760 mmHg.
- The primary components of this pressure is nitrogen, oxygen, argon and carbon dioxide.

Components of atmosphere :

Composition of dry air	
Substance	% by volume
Nitrogen (N_2)	78.08
Oxygen (O_2)	20.95
Argon (Ar)	0.93
Carbondioxide (Co_2)	0.033
Neon (Ne)	0.0018
Helium (He)	0.00052
methane (CH_4)	0.0002
Krypton (Kr)	0.00011
Nitrogen oxide (N2O)	0.00005
Hydrogen (H2)	0.00005

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Partial pressure :

- The pressure exerted by an individual gas in a mixture of gases.
- Designated by PGAS.
- To determine the partial pressure of any gas, multiply the percentage of that gas by the total pressure.

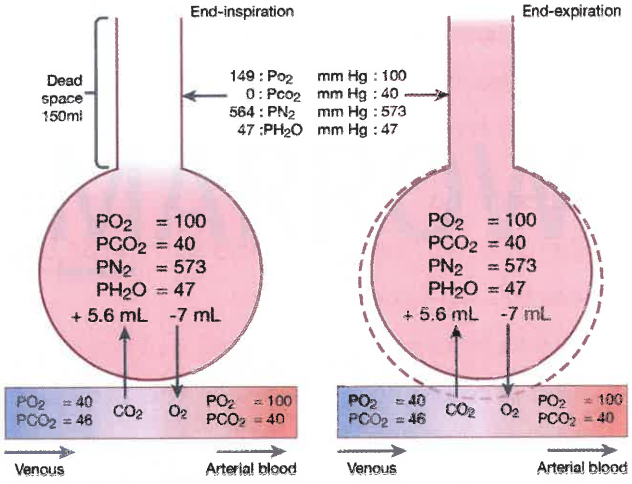
  Example : Oxygen occupies 21% of the atmosphere. If the total pressure of the atmosphere (i.e. barometric pressure) is 760 mmHg, the PO2 of the atmosphere is 159.6 mmHg (760 x .21).

Partial pressure of key gases :

Oxygen partial pressure is reduced as it goes from the atmosphere to the alveoli secondary to "competition" with carbon dioxide and water vapor.

Partial pressure of O_a and CO_a :

- The partial pressure of O_a is significantly lower in the alveoli than in the atmosphere.
- If you imagine the alveoli as a micro-environment the CO_a level and water vapor content are much higher.
- By the time the atmospheric gas reaches the alveoli they are diluted by CO_a and H_aO.



Partial pressure of key gases

Water vapour pressure :

- When water vapor is present in a volume of gas it exerts its own partial pressure in accordance with Daltons Law.
- Alveolar gas is 100% humidified at body temp.
- It is assumed to have an absolute humidity of 44mg/L and a partial pressure of (PH_aO) of 47 mmHg.

Temperature	Absolute (maximum) Humidity	Water vapour pressure
37°C	44.0 mg/L	47.0 mmHg
35°C	39.6 mg/L	42.2 mmHg
30°C	30.4 mg/L	31.8 mmHg
27°C	25.8 mg/L	26.7 mmHg
25°C	23.0 mg/L	23.8 mmHg
20°C	17.3 mg/L	17.5 mmHg

Alveolar gas equation :

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- Thus, alveolar oxygen (PAO_2) is calculated using the "ideal alveolar gas equation" or " the alveolar gas equation".

$$PAO_2 = [PB - PH_2O]FIO_2 - Paco_2 / R$$

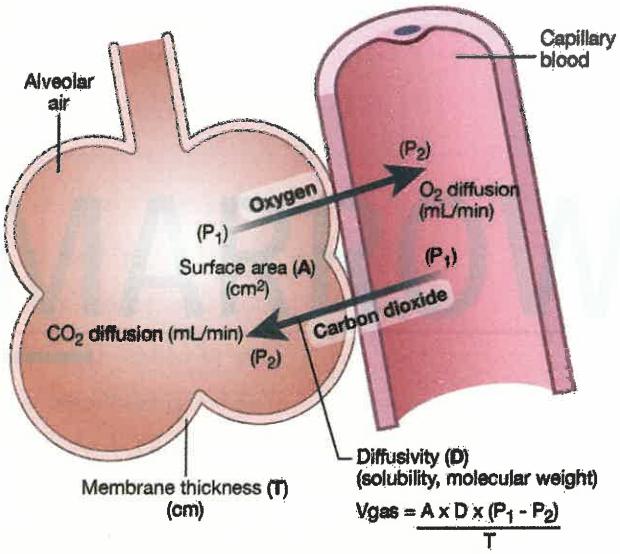
- This equation computes the total PIO_2 available for oxygen transfer.

Factors affecting gas exchange 00:08:08

These factors affect the gas exchange at the alveolo capillary level.

Fick's law :

- Given by Adolph Fick (1831 – 1879).
- The law states that the rate of gas transfer across a sheet of tissue is directly proportional to :
  i. Surface area of the tissue (A).
  ii. Diffusion constant (D).
  iii. Difference in partial pressure of the gas between the two sides of the tissue (P).
  iv. Inversely proportional to the thickness of the tissue (T).
- $V = [A \times D \times (P1 - P2)] / T$.
- Gas moves from alveoli to capillary because of a pressure gradient.



Diffusion of gas across alveolar capillary membrane

Henry's law :

The amount of gas that can be dissolved by 1 mL of a given liquid at standard pressure (760 mm Hg) and at a specified temperature is called the solubility coefficient.

- The solubility coefficient varies inversely with temperature.
- For oxygen at 37° C the coefficient is 0.0244 ml/mm Hg/mL H2O.
- For carbon dioxide it is 0.592 ml/mm Hg/mL H2O.
- In a liquid medium (Like the blood and interstitial space), carbon dioxide is 24 times more soluble.

Henry's law states that the amount of a gas that dissolves in a liquid at a given temperature is proportional to the partial pressure of the gas.

$$\text{Partial pressure} = \frac{\text{Concentration of dissolved gas}}{\text{Solubility coefficient}}$$

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Gas	Solubility coefficient
Oxygen	0.024
Carbon dioxide	0.57
Carbon monoxide	0.018
Nitrogen	0.012
Helium	0.008

Graham's law :

- Graham's law states that the rate of diffusion of a gas through a liquid is :
  i. Directly proportional to the solubility coefficient of the gas.
  ii. Inversely proportional to the square root of the gram-molecular weight of the gas.
- The diffusion rate of CO_2 is 20 times greater than that of O_2.

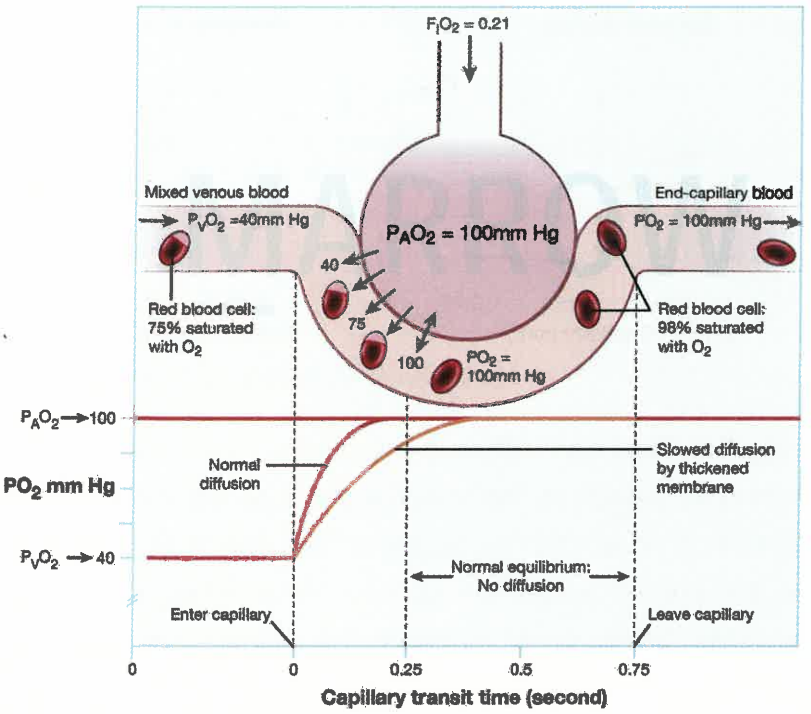
Summary :

- The greater the solubility of the gas, the greater the number of molecules available to diffuse for any given partial pressure difference.
- The greater the cross-sectional area of the diffusion pathway, the greater the total number of molecules that diffuse.
- Conversely, the greater the distance the molecules must diffuse, the longer it will take the molecules to diffuse the entire distance.
- Finally, the greater the velocity of kinetic movement of the molecules, which is inversely proportional to the square root of the molecular weight, the greater the rate of diffusion of the gas.

Time interval of diffusion :

- Diffusion of oxygen and carbon dioxide occurs because of a pressure gradient.
- The diffusion of O_2 and CO2 will continue until equilibrium is reached between the two gases; this is usually accomplished in about 0.25 second out of 0.75 sec total.
- Under normal resting conditions, the total transit time for blood to move through the A/C system is about 0.75 second.

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Perfusion limited gas transport

Exercise and diffusion :

- During exercise, the transit time can be reduced to as low as 0.40 seconds.
- Increased cardiac output, decreased transit time (Less time spent in the capillary in front of a alveolus).
- Since only 0.25 seconds required for complete diffusion : Normal patient can maintain oxygenation during exercise.

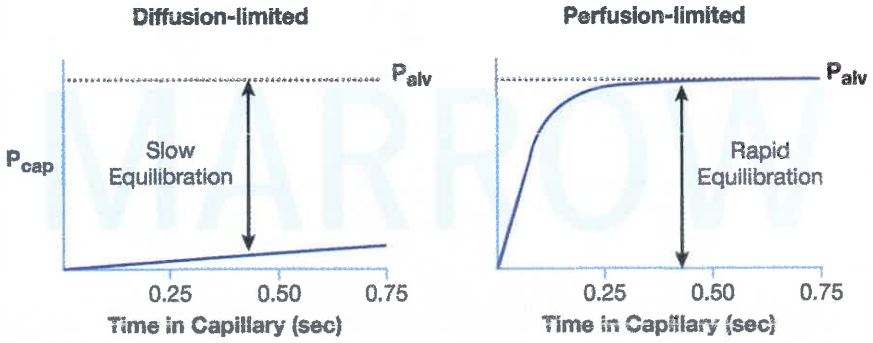
Diffusion during exercise :

- In the presence of certain pulmonary diseases, the time required to achieve oxygen equilibrium in the A/C system may not be adequate.
- Such diseases include alveolar fibrosis, alveolar consolidation, and pulmonary edema.

Clinical application of Fick's law :

- Decreased alveolar surface area (Atelectasis) : Decreases the ability of O2 to enter the pulmonary capillary blood.
- Decreased alveolar O2 pressure (High altitudes) : Reduces the diffusion of O2 into the pulmonary capillary blood.
- Increased alveolar tissue thickness (Pulmonary fibrosis, pulmonary edema) : Reduces the movement of O2 across the A/C system.

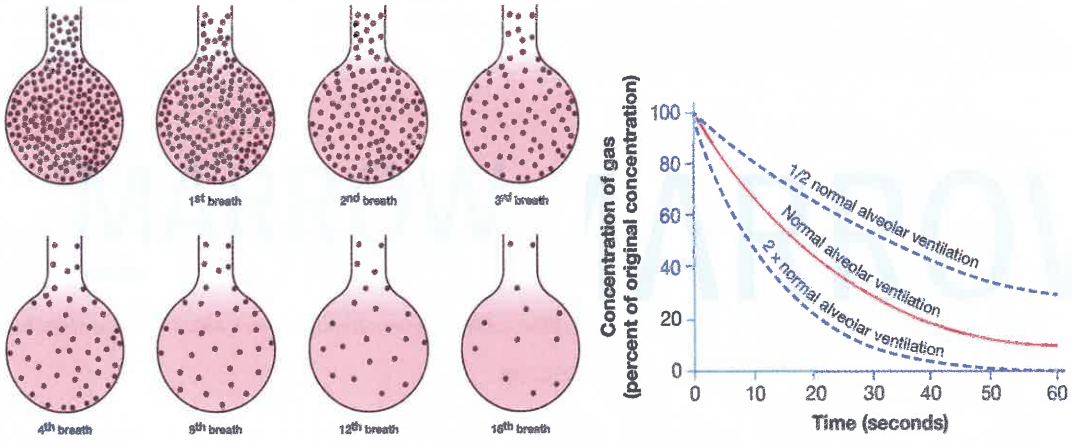
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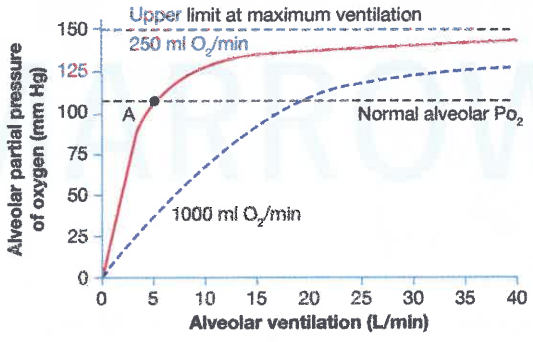
Diffusion of gases

Alveolar ventilation and gas diffusion :

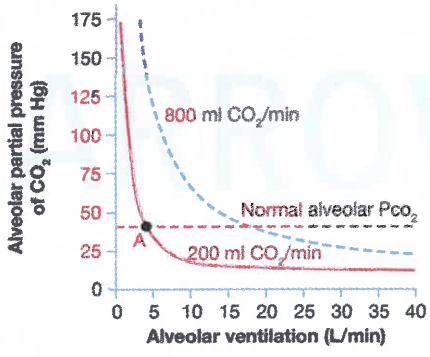
- Concentration of oxygen in the alveoli is more during initial ventilation .
- As the ventilation increases the oxygen in the alveoli gets diluted.
- When the demand of oxygen increases in case of hypoxia , burns the respiratory rate increases to maintain the oxygen levels inside the alveoli.



Alveolar ventilation



Alveolar ventilation according to demand of oxygen



Alveolar ventilation in increased CO_a levels

In case of increased carbondioxide levels the alveolar ventilation increases to maintain the required oxygen levels.

Perfusion of gas

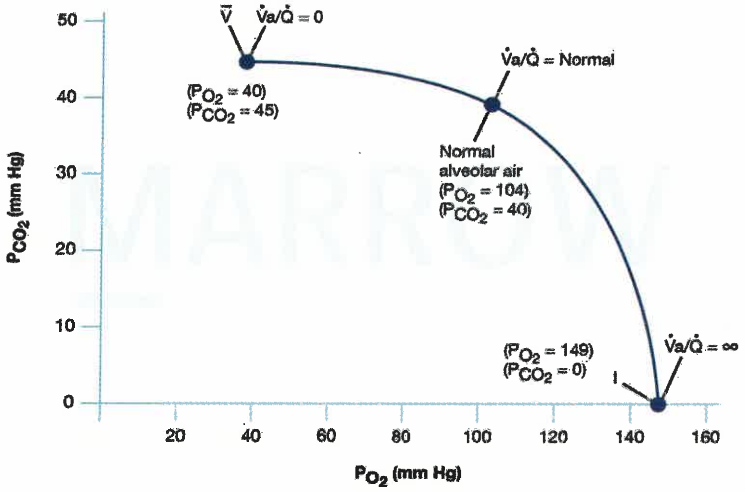
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Effect of perfusion on alveolar gas transfer across A – C membrane :

Ventilation is zero :

- V/Q = 0.
- Ventilation is zero while perfusion is present.
- Partial pressures will mimic that of venous gas because the venous capillaries bypasses and directly ends in arterial end.
- There is no gas exchange.
- Arterial partial pressure is similar to gases in venous end.
- This is called shunt.



Ventilation perfusion ratio

Normal lung :

- Ventilation and perfusion is present.
- There is $\uparrow PO_{a}$ $\downarrow PCO_{a}$.
- Gas exchange takes place.

Ventilation is present but no perfusion :

- Ventilation is positive but perfusion is zero.
- V/Q is infinity.
- Venous end is not communicating with alveoli , so the alveoli is having arterial oxygenation.
- Arterial oxygen concentration is equivalent to PI49.
- There is no carbon dioxide transfer.
- This is called dead space.

Concept of dead space :

Two types :

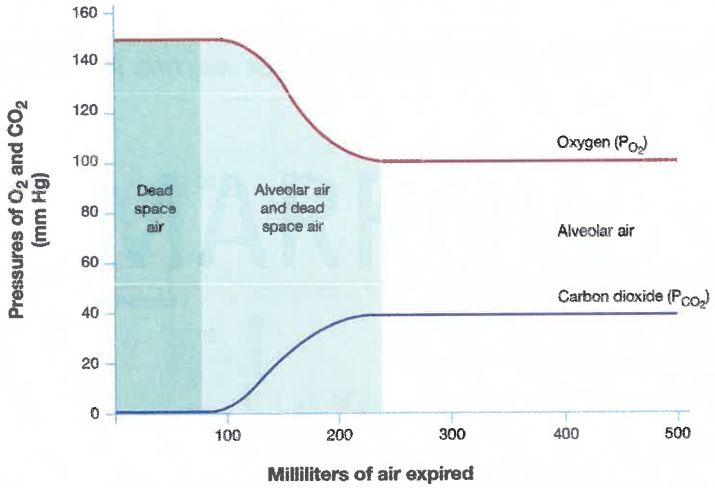
- Anatomical dead space : Does not take part in gas exchange.
- Physiological dead space : Gas in the alveoli that does not have perfusion contributes to physiological dead space.

Note :

- Initial breath will have gas present in anatomical dead space and the breath between 100 to 200 milliseconds will have gas combined with alveolar air and dead space air.

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- After reaching a plateau it will have air from alveolar ventilation.



Dead space

Shunt :

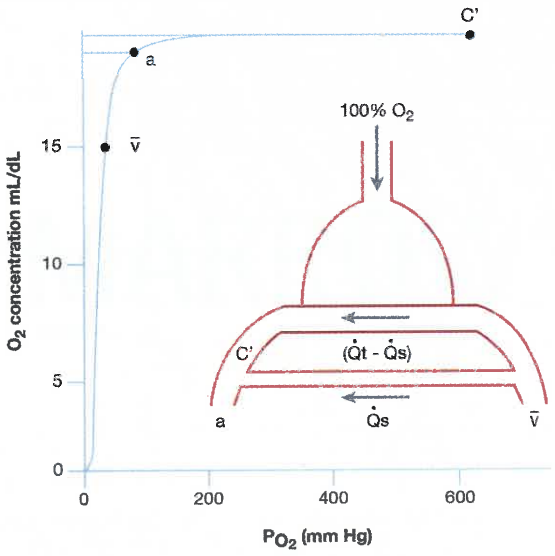
- Some part of pulmonary capillary blood is not oxygenated and a part of cardiac output goes to bronchial vessels.
- Some of the alveoli are not ventilated.
- ↑ in Physiological shunt → Deoxygenated blood leaving the lungs is ↑ (Base of lung).
- ↑ in Physiological dead space → Wasted ventilation proportion is ↑ (Apex of lung).

$$\frac{Q_{PS}}{Q_T} = \frac{Ci_{O_2} - Ca_{O_2}}{Ci_{O_2} - Cv_{O_2}}$$

This formula is derived from Fick's principle.

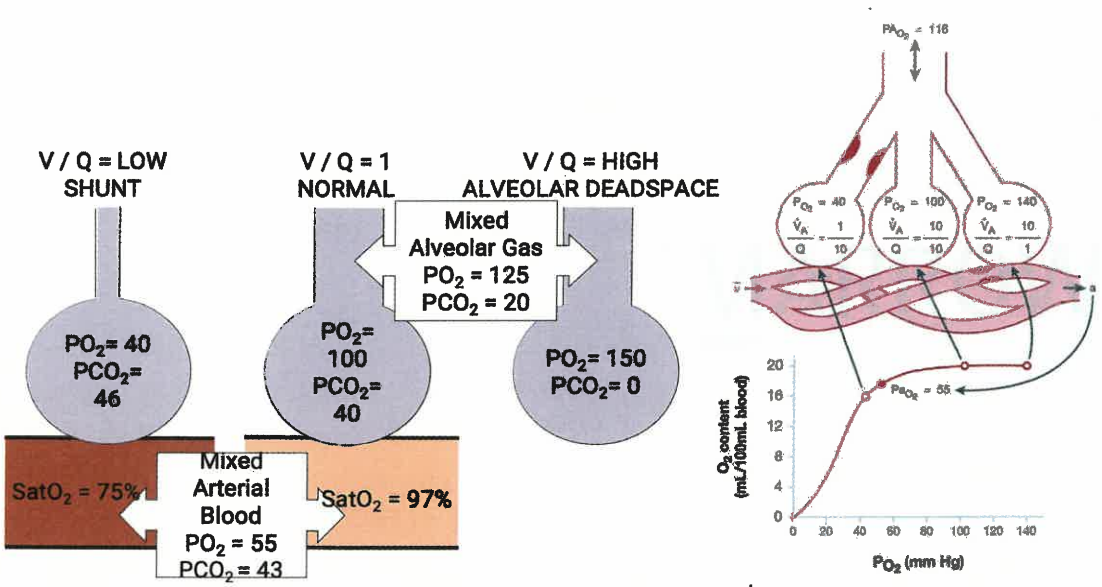
Dead space is calculated by the formula :

$$\frac{V_{Dphys}}{V_T} = \frac{Pa_{CO_2} - PE_{CO_2}}{Pa_{CO_2}}$$



Shunt

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Three compartment model of V/Q

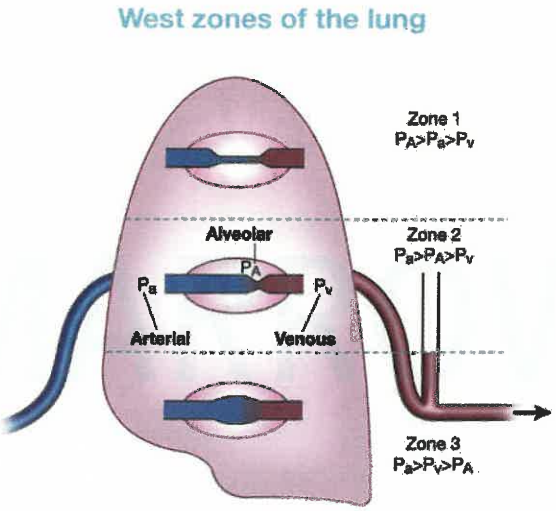
more shunt → more hypoxia ($\downarrow PO_2$).

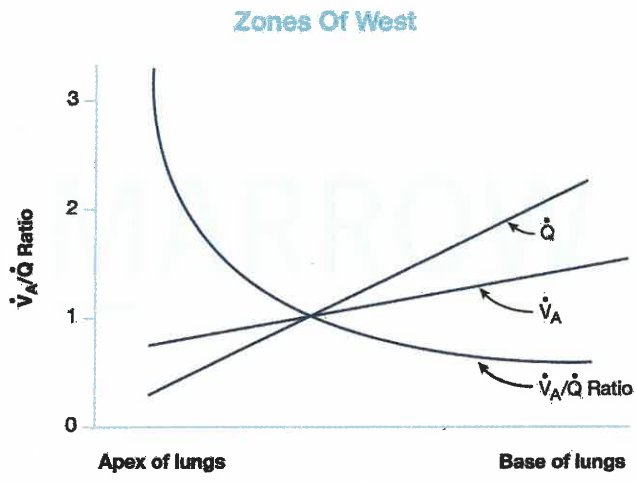
more dead space → more carbon dioxide retention.

Inspite 100% oxygenation if there is no improvement in saturation it indicates that there is increased shunting. It is also seen in severe diffusion restriction.

Zones of west :

- Zone I (Apex of the lung) : Alveolar pressure(P_A)> pulmonary arterial (P_a)> pulmonary venous (P_v) → Increased dead space.
- Zone II : $P_a > P_A > P_v$ → Normal oxygenation.
- Zone III : $P_a > P_v > P_A$.





West zone of lung