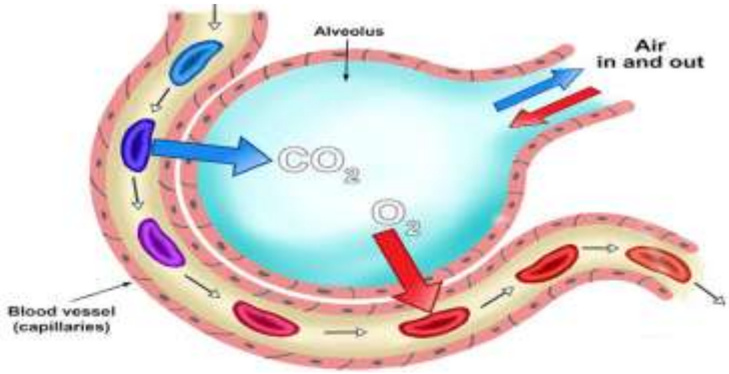


# Lecture 11: Mechanism of gas diffusion

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***Learning Objective :***

***Knowledge:***

- Understand factors affecting diffusion through the respiratory membrane.
- Explain factors affecting pulmonary circulation and the interaction between respiration and the circulation.
- Know effect of high partial pressure of gases on the respiratory system.
- State ventilation –perfusion ratio. V/Q
- Understand Ventilation/perfusion matching and its effect on blood O 2 and CO 2 content.

**Intellectual:**

Explore the mismatch V/Q ratio

# Diffusion of gases through the pulmonary membrane

- Gaseous exchange between alveolar air and the pulmonary blood occurs through the membrane of all terminal portions of the lungs. These membranes are known as <u>*Pulmonary OR Respiratory membrane .*</u>
- The gases in these two compartments are brought into close contact with each other $O_2$ and $CO_2$ move in opposite directions, across the blood–gas barrier, by simple diffusion
- The very large surface area of pulmonary capillaries and alveoli, as well as the close apposition of these structures, make the lungs a very efficient device for mediating gas exchange.

**Factors affecting rate of diffusion through the respiratory membrane**

**1-The structure of the blood–gas barrier is optimized for rapid gas exchange as:**

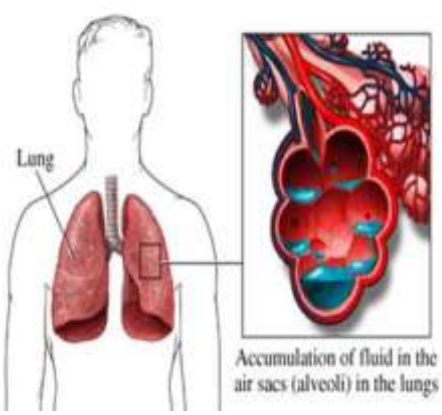
a. <u>*Area of the pulmonary membrane :*</u> The total surface area of the alveoli is large (80–140$m^2$). The rate of diffusion is proportional to the area.

- Decreased surface area ( e.g. Emphysema)

-↑ surface area during muscular exercise (opened capillaries).

b. <u>*Thickness of the pulmonary membrane (diffusion distance)*</u>: Only 0.3μm. The rate of diffusion is inversely proportional to the thickness of the barrier.

-The increased distance can be due to interstitial edema.




<u>*2- Partial pressure difference of the gas*</u>: The rate at which gas moves from a region of high partial pressure to a region of low partial pressure is proportional to the partial

pressure difference of these gases across the membrane and the area available for diffusion.

- At altitude (when the partial pressure gradient for $O_2$ is reduced), the transport of $O_2$ can become diffusion limited

*3.Lipid solubility*: At $37^0$C, $CO_2$ is about 20 times more soluble in water than $O_2$, and, since they are of similar molecular weight, the rate of diffusion of $CO_2$ is much greater, even though the partial pressure gradient for CO2 is not as great.

## Pulmonary Circulation

**Pulmonary Blood Flow:**

- Lungs receive the whole amount of blood that is pumped out from right ventricle. Output of blood per minute is same in both right and left ventricle. It is about 5 liter.
- Thus, the lungs accommodate amount of blood, which is equal to amount of blood accommodated by all other parts of the body.

**Pulmonary Blood Pressure:**

- Pulmonary blood vessels are more distensible than systemic blood vessels. So the blood pressure is less in pulmonary blood vessels. Thus, the entire pulmonary vascular system is a **low pressure bed.**
- The mean pressure within the pulmonary system is lower than the systemic circulation, largely because the height through which blood is required to ascend is significantly less.
- So, the total resistance of the pulmonary system is much lower. This is largely because the muscular arterioles which are the major resistance vessel of the systemic circulation are not present in the pulmonary circulation.

***Pulmonary Capillary Pressure***

- The normal pulmonary capillary pressure is about 7 mm Hg. This pressure is sufficient for exchange of gases between alveoli and blood.

- The mean pressure within the pulmonary system is 15 mmHg, with systolic and diastolic pressures of 25mmHg and 8mmHg, respectively.

***Clinical Application:***

Pulmonary Edema:

is the accumulation of serous fluid either in the alveoli or the interstitial tissue of lungs.

Causes:

1- Greatly Increased pulmonary capillary pressure due to left ventricular failure or mitral valve disease

2- Locally capillary damaged in the lungs as in:

- Bacterial infection: as in Pneumonia
- Breathing harmful chemicals like chlorine or sulfur dioxide.

***Pulmonary edema safety factor:***

The normal pulmonary capillary pressure is 7 mmHg, he plasma colloid osmotic pressure is 28mmHg. ***Then the pulmonary capillary pressure must rise more than 28 mmHg to cause pulmonary edema, giving safety factor against pulmonary edema of about 21 mmHg.***

**1-Effect of hydrostatic pressure gradient on pulmonary blood flow distribution:**

- The blood pressure in the foot of a standing person can be as much as 90 mm Hg greater than the pressure at the level of the heart. This is caused by *hydrostatic pressure—that is, by the weight of the blood itself in the blood vessels*.
- The same effect, but to a lesser degree, occurs in the lungs. In the normal, upright adult, about 15 mm Hg is above the heart and 8 below (23 mm Hg pressure difference).

**Zones 1, 2, and 3 of Pulmonary Blood Flow:**

- The capillaries in the alveolar walls are distended by the blood pressure inside them, but simultaneously, they are compressed by the alveolar air pressure on their outsides.

- Therefore, any time the lung alveolar air pressure becomes greater than the capillary blood pressure, the capillaries close and there is no blood flow. Under different normal and pathological lung conditions, one may find any one of three possible zones of pulmonary blood flow, as follows:

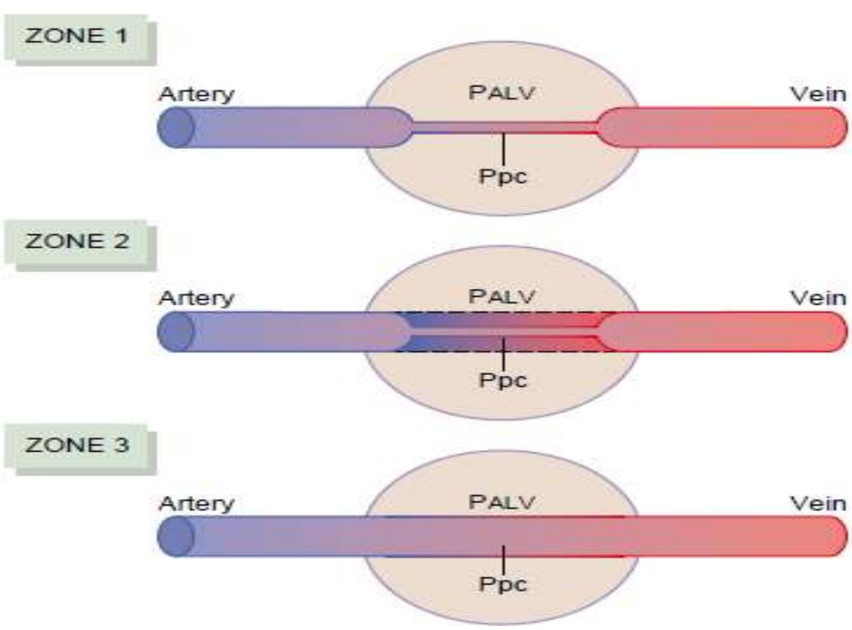
  *Zone 1: No blood flow during all portions of the cardiac cycle* because the local alveolar capillary pressure in that area of the lung never rises higher than the alveolar air pressure during any part of the cardiac cycle.

  *Zone 2: Intermittent blood flow:* only during the pulmonary arterial pressure peaks because the systolic pressure is then greater than the alveolar air pressure, but the diastolic pressure is less than the alveolar air pressure.

*Zone 3: Continuous blood flow* because the alveolar capillary pressure remains greater than alveolar air pressure during the entire cardiac cycle

***Normally***, the lungs have only zones 2 and 3 blood flow—zone 2 (intermittent flow) in the apices, and zone 3 (continuous flow) in all the lower areas.

**N.B.:** *Zone* 1 blood flow occurs only under abnormal conditions as in an upright person whose pulmonary systolic arterial pressure is exceedingly low, as might occur after severe blood loss.



**2- Effect of Exercise on Blood Flow Through the Different Parts of the Lungs:**

- The blood flow in all parts of the lung increases during exercise.
- The increase in blood flow is due to that the pulmonary vascular pressures rise enough during exercise to convert the lung parts from a zone 2 pattern into a zone 3 pattern of flow. Thus the increase in flow in the above part of the lung is much higher than the lower part of the lung.

**3- Hypoxic vasoconstriction (Automatic Control of Pulmonary Blood Flow Distribution:**

- Hypoxic regions of the lungs undergo vascular vasoconstriction.
- Below 100mmHg $PO_2$, rapid vasoconstriction occurs.
- The precise mechanism underlying this is unknown (although it is believed to involve an increase in or sensitization to $Ca^{2+}$ in vascular smooth muscle cells.
- Hypoxic vasoconstriction directs blood flow towards better-ventilated regions of the lung (Auoregulation). At high altitude, hypoxic vasoconstriction increases pulmonary blood pressure and can cause oedema

*Significance:*

- That is, if some alveoli are poorly ventilated so that their oxygen concentration becomes low, the local vessels constrict.
- This causes the blood to flow through other areas of the lungs that are better aerated, thus providing an automatic control system for distributing blood flow to the pulmonary areas in proportion to their alveolar oxygen pressures.

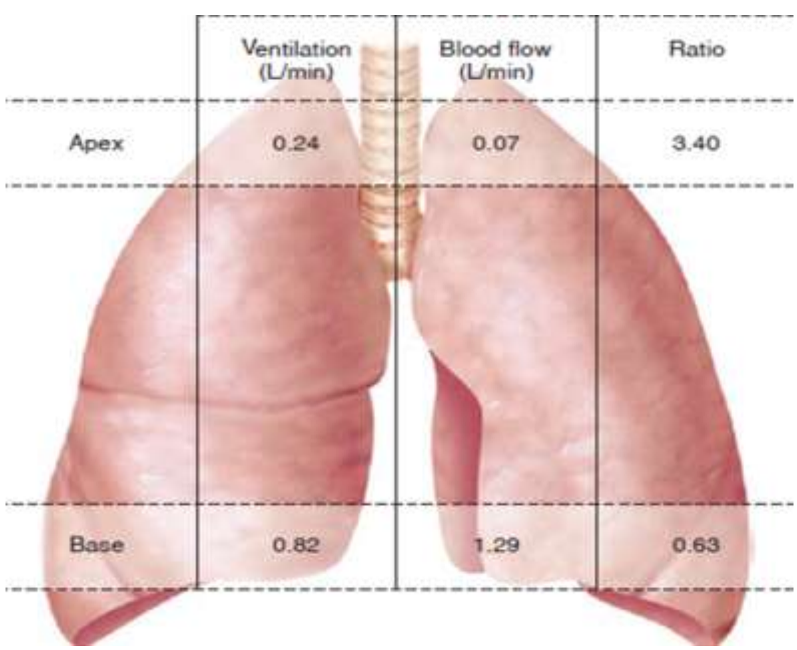
**Ventilation–perfusion Relationships**

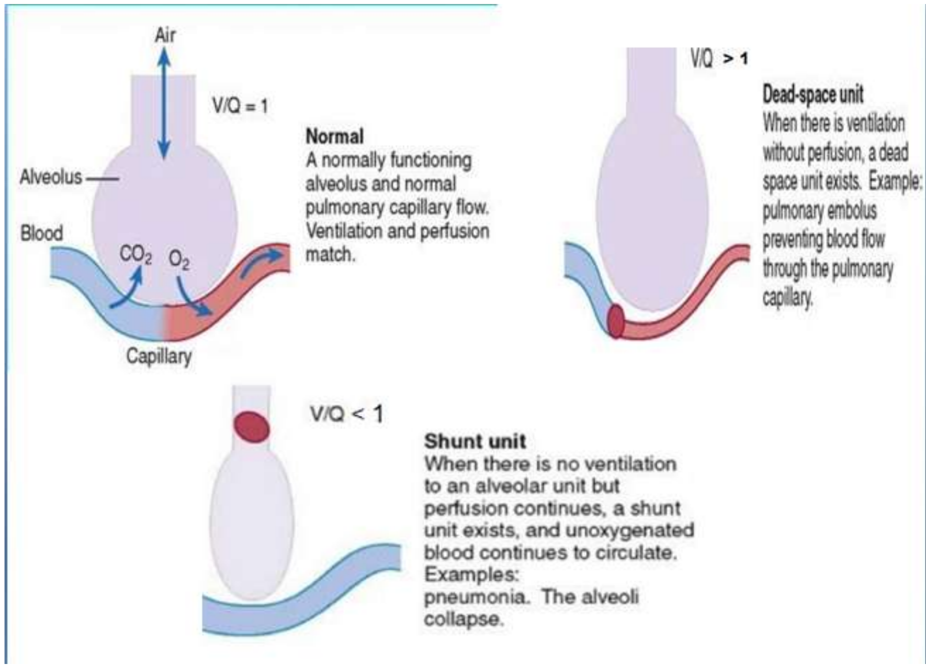
- In an ideal pair of lungs all the alveoli would be supplied with equal volumes of air of uniform gas composition during inspiration.
- The matching of ventilation and perfusion in all regions of the lung is a critical determinant of healthy gas exchange. *The ventilation–perfusion (V/Q) ratio is a useful measure of this matching.*

- Ventilation and perfusion are both higher at the bottom of the lung, ***but perfusion varies to a greater extent than ventilation*** and ***gravity*** is the most responsible factor for these differences.

***Lung ventilation – perfusion ratio: The V/P ratios indicate that the apex is relatively over ventilated and base is under ventilated in relation to their blood flow.***

- Perfusion varies to a greater extent than ventilation because the density of blood is greater than that of inspired air.
- The V/Q ratio is therefore *greatest at the apex* of the lung and least at its base.
- In well-ventilated, well-perfused alveoli (V/Q-1), means that blood equilibrates with alveolar air.
- In poorly ventilated but well perfused alveoli (V/Q < 1 ).
- In well-ventilated but poorly perfused alveoli (V/Q > 1).






## Disorders Caused by High Partial Pressures of Gases

***Decompression sickness (Diver's disease)***

- It is life threatening condition caused by a build up of nitrogen bubbles in the blood stream and body tissues.
- At normal atmospheric pressure, some nitrogen and oxygen is dissolved in the fluid portions of your blood and tissues.
- As the diver ascends to sea level, the amount of nitrogen dissolved in the plasma decreases as a result of the progressive decrease in the $PN_2$ .
- Under the water, the pressure on your body increases, so more nitrogen and oxygen dissolve in the blood. Most of the oxygen gets consumed by the tissues, but the nitrogen remains dissolved.
- If the diver surfaces slowly, a large amount of nitrogen can diffuse through the alveoli and be eliminated in the expired breath.
- If decompression occurs too rapidly, however, large amount of N2 diffuses from high pressure (alveoli) to low pressure (blood).

- The bubbles of $N_2$ in the blood can block small blood vessels, forming gas embolism producing muscle and joint pain as well as more serious damage.