Gas exchange-2

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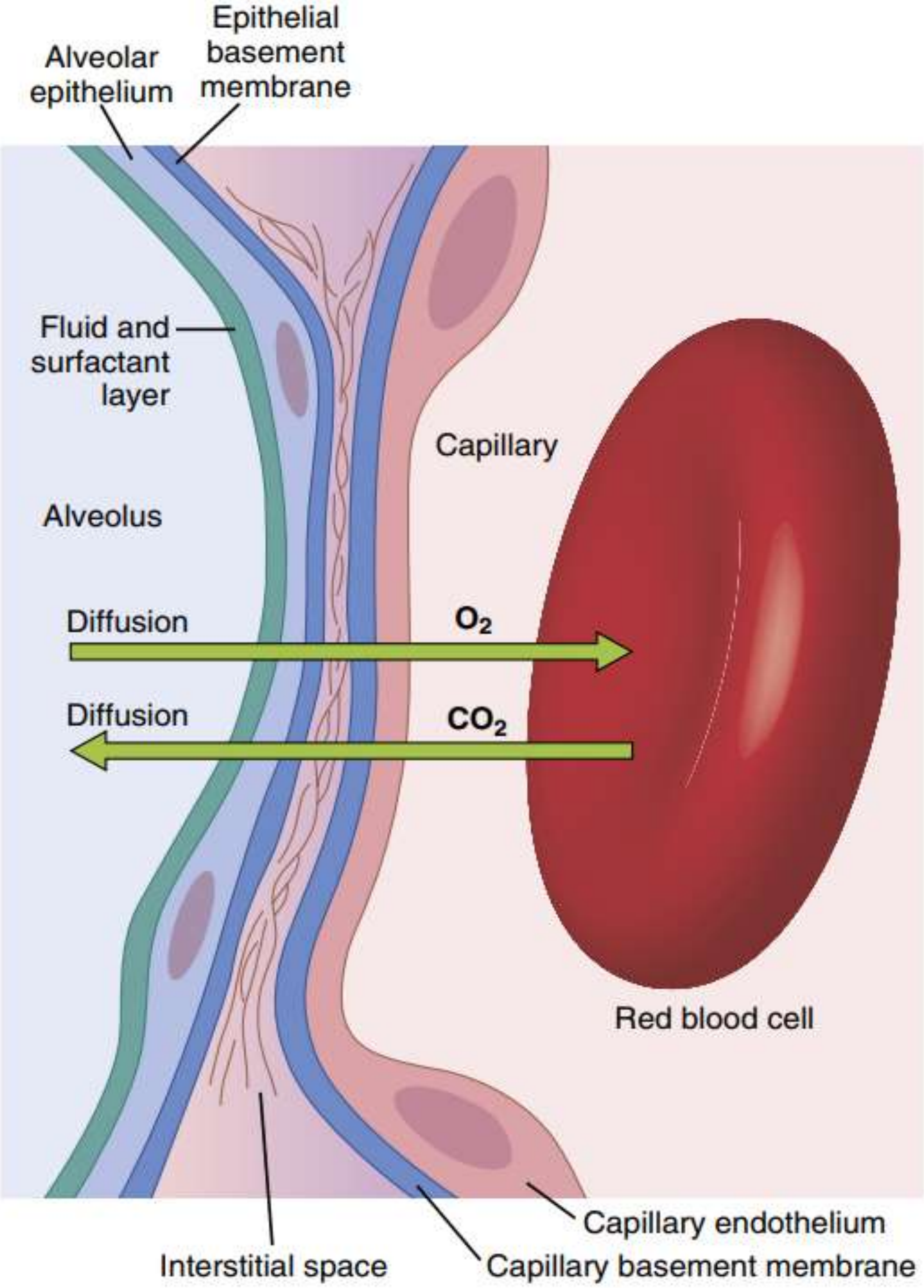
Respiratory membrane

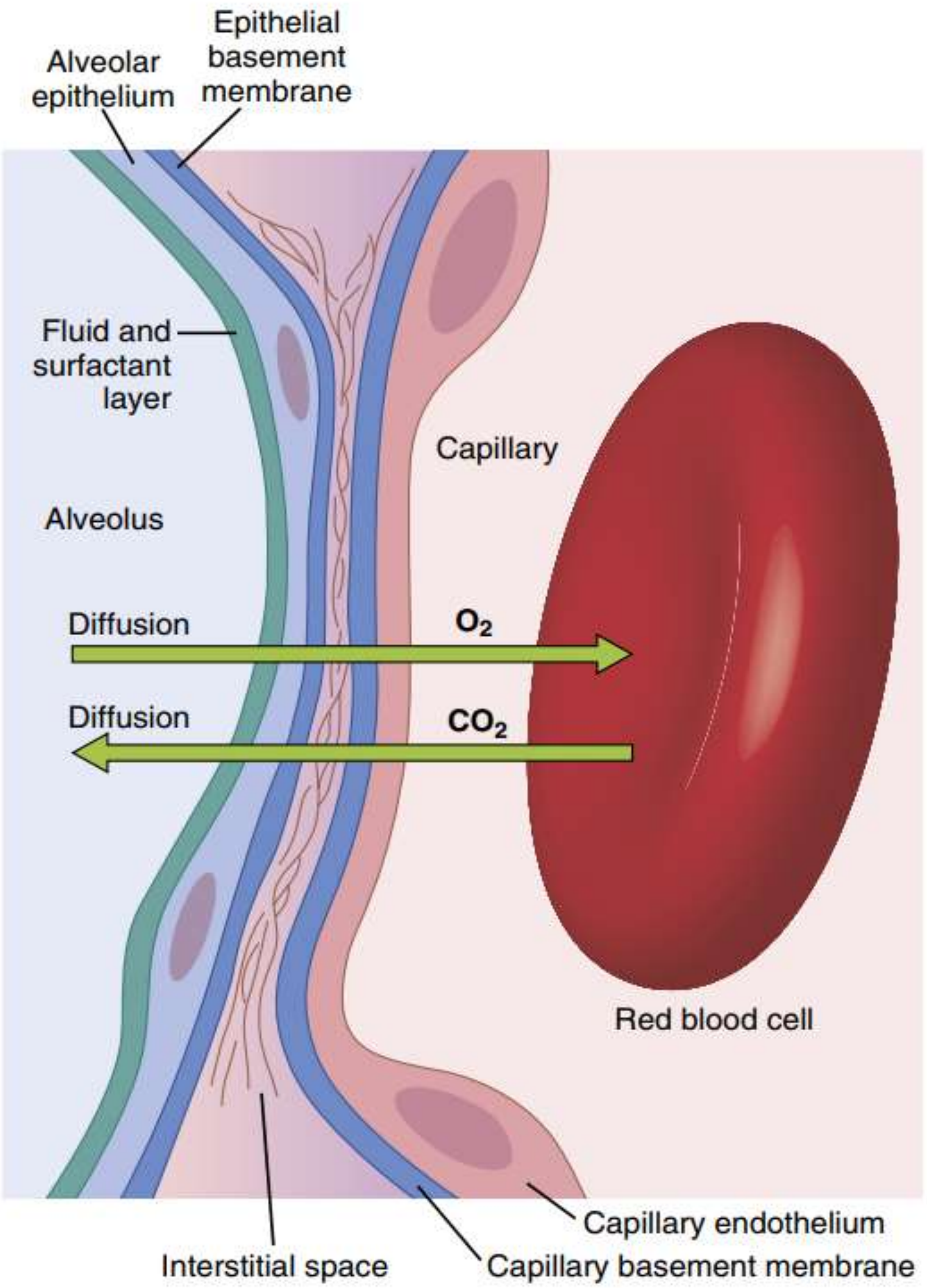


Rapid gas diffusion rate

0.2-0.6 micrometer thickness (fibrosis, edema).
70 m2 surface area (emphysema).
60-140 mL blood in pulmonary capillaries
5 micrometer diameter of capillaries

the diffusion coefficient of the gas (solubility, MW).

the partial pressure difference of the gas between the two sides of the membrane.



Lung diffusing capacity (DL)

- The ability of the respiratory membrane to exchange a gas between the alveoli and pulmonary blood is expressed in quantitative terms by the respiratory membrane's diffusing capacity.

- The volume of a gas that will diffuse through the membrane each minute for a partial pressure difference of 1 mm Hg.

$$\dot{V}x = \frac{DA\Delta P}{\Delta x}$$

where

$\dot{V}x$ = Volume of gas transferred per unit time

D = Diffusion coefficient of the gas

A = Surface area

ΔP = Partial pressure difference of the gas

Δx = Thickness of the membrane

Lung diffusing capacity (DL)

- DL combines the diffusion coefficient of the gas, the surface area of the membrane (A), and the thickness of the membrane (ΔX).

- DL also takes into account the time required for the gas to combine with proteins in pulmonary capillary blood (e.g., binding of O2 to hemoglobin in red cells).

Lung diffusing capacity (DL)

- DL can be measured with carbon monoxide (CO) because CO transfer across the alveolar/pulmonary capillary barrier is limited exclusively by the diffusion process.
- DLCO is measured using the single breath method where the subject breathes a gas mixture containing a low concentration of CO; the rate of disappearance of CO from the gas mixture is proportional to DL.

O_2 diffusing capacity

- The average diffusing capacity for CO in healthy young men at rest is 17 ml/min per mm Hg, and the diffusing capacity for O_2 is 1.23 times this.

- The diffusing capacity for O_2 under resting conditions averages 21 ml/min per mm Hg.

- About 230 ml of oxygen diffusing through the respiratory membrane each minute, which is equal to the rate at which the resting body uses O_2.

- A diffusing capacity for CO_2 under resting conditions of about 400 to 450 ml/min per mm Hg.

Lung diffusing capacity (DL)

- In various diseases, DL changes in a predictable way.
- **In emphysema**, for example, DL decreases because destruction of alveoli results in a decreased surface area for gas exchange.
- **In fibrosis or pulmonary edema**, DL decreases because the diffusion distance (membrane thickness or interstitial volume) increases.
- **In anemia**, DL decreases because the amount of hemoglobin in red blood cells is reduced (recall that DL includes the protein-binding component of O2 exchange).
- **During exercise**, DL increases because additional capillaries are perfused with blood, which increases the surface area for gas exchange.

Gases in a solution

- In alveolar air, there is one form of gas, which is expressed as a partial pressure.

- However, in solutions such as blood, gases are carried in additional forms. In solution, gas may be dissolved, it may be bound to proteins, or it may be chemically modified.

- It is important to understand that the total gas concentration in solution is the sum of dissolved gas plus bound gas plus chemically modified gas.

Dissolved gas

- Of the gases found in inspired air, nitrogen (N_2) is the only one that is carried only in dissolved form and it is never bound or chemically modified.

- Because of this simplifying characteristic, N_2 is used for certain measurements in respiratory physiology.

Dissolved gas

- All gases in solution are carried, to some extent, in the dissolved form.
- Henry’s law gives the relationship between the partial pressure of a gas and its concentration in solution: For a given partial pressure, the higher the solubility of the gas, the higher the concentration of gas in solution.
- In solution, only dissolved gas molecules contribute to the partial pressure. In other words, bound gas and chemically modified gas do not contribute to the partial pressure.

Bound gas

- O_2, CO_2, and CO are bound to proteins in blood.
- O_2 and CO bind to hemoglobin inside red blood cells and are carried in this form.
- CO_2 binds to hemoglobin in red blood cells and to plasma proteins.

Chemically modified gas

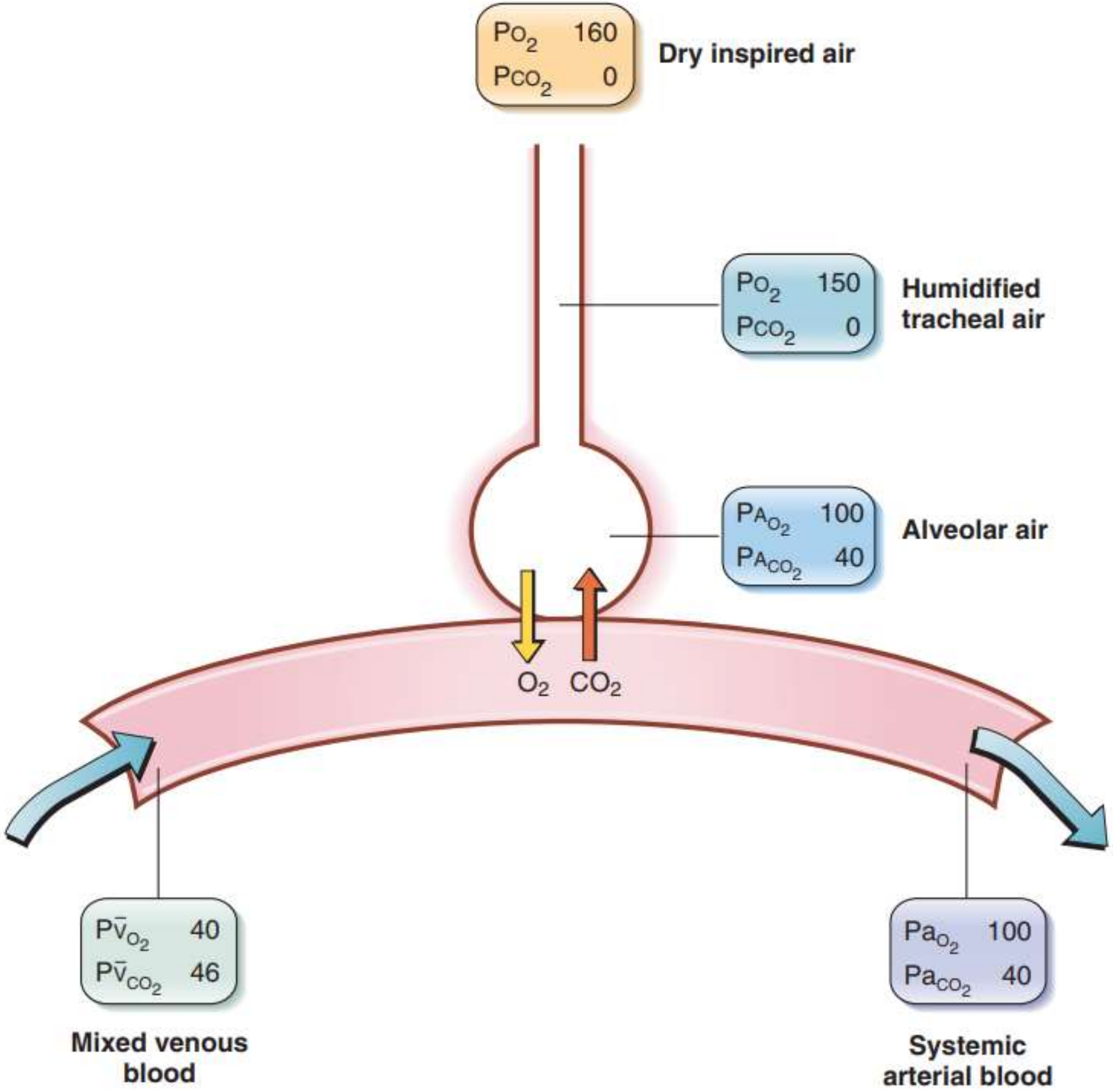
- The most significant example of a chemically modified gas is the conversion of CO_2 to bicarbonate (HCO_3^-) in red blood cells by the action of carbonic anhydrase.

- In fact, most CO_2 is carried in blood as HCO_3^-, rather than as dissolved CO_2 or as bound CO_2.

Gas transport in the lungs

- Normally, the amounts of O_2 and CO_2 transferred between the alveoli and pulmonary capillary blood correspond to the needs of the body.

- Thus, on a daily basis, O_2 transfer from alveolar air equals O_2 consumption by the body, and CO_2 transfer to alveolar air equals CO_2 production.



Po2 160
Pco2 0
Dry inspired air
Po2 150
Pco2 0
Humidified tracheal air
PAO2 100
PACO2 40
Alveolar air
O2 CO2
Pv̄O2 40
Pv̄CO2 46
Mixed venous blood
PaO2 100
PaCO2 40
Systemic arterial blood

Mixed venous blood

- Blood entering the pulmonary capillaries is mixed venous blood.
- This blood has been returned from the tissues, via the veins, to the right heart. It is then pumped from the right ventricle into the pulmonary artery, which delivers it to the pulmonary capillaries.
- The composition of this mixed venous blood reflects metabolic activity of the tissues.
- The PO_2 is relatively low, at 40 mm Hg, because the tissues have taken up and consumed O_2; the PCO_2 is relatively high, at 46 mm Hg, because the tissues have produced CO_2 and added it to venous blood.

Systemic arterial blood

- Because diffusion of gases across the alveolar/capillary barrier is rapid, blood leaving the pulmonary capillaries normally has the same PO_2 and PCO_2 as alveolar air (i.e., there is complete equilibration).

- Hence, PaO_2 is 100 mm Hg and $PaCO_2$ is 40 mm Hg, just as PAO_2 is 100 mm Hg and $PACO_2$ is 40 mm Hg.

Physiologic shunt

- There is a small discrepancy between alveolar air and systemic arterial blood:

- Systemic arterial blood has a slightly lower PO_2 than alveolar air.

- This discrepancy is the result of a physiologic shunt, which describes the small fraction of pulmonary blood flow that bypasses the alveoli and therefore is not arterialized.

Physiologic shunt

- The physiologic shunt has two sources:
- **bronchial blood flow and a small portion of coronary venous blood** that drains into the left side of the heart rather than going to the lungs to be oxygenated.

- The physiologic shunt is increased in several pathologic conditions (called a ventilation/perfusion defect).

Diffusion-limited gas exchange

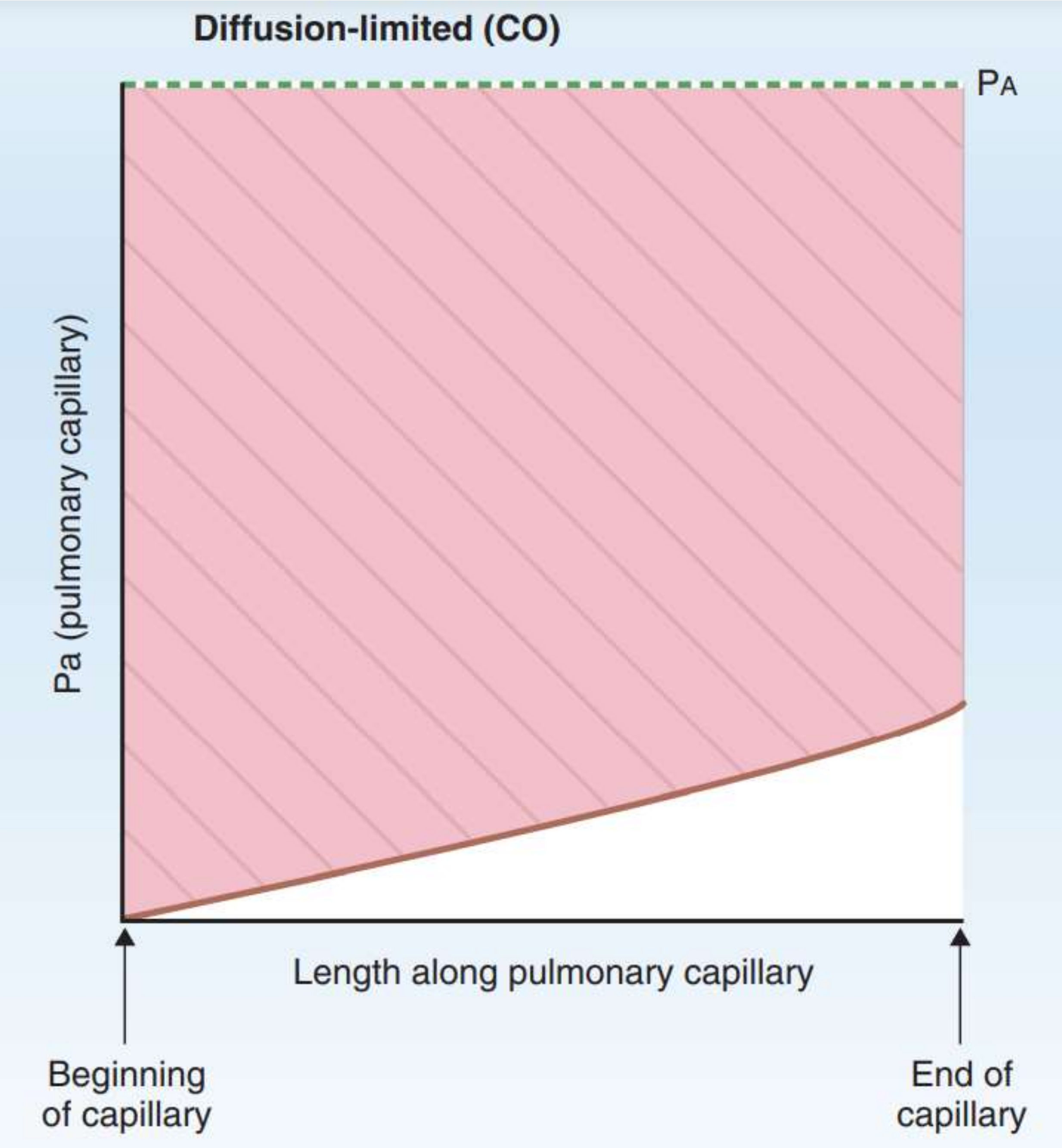
- The total amount of gas transported across the alveolar-capillary barrier is limited by the diffusion process.

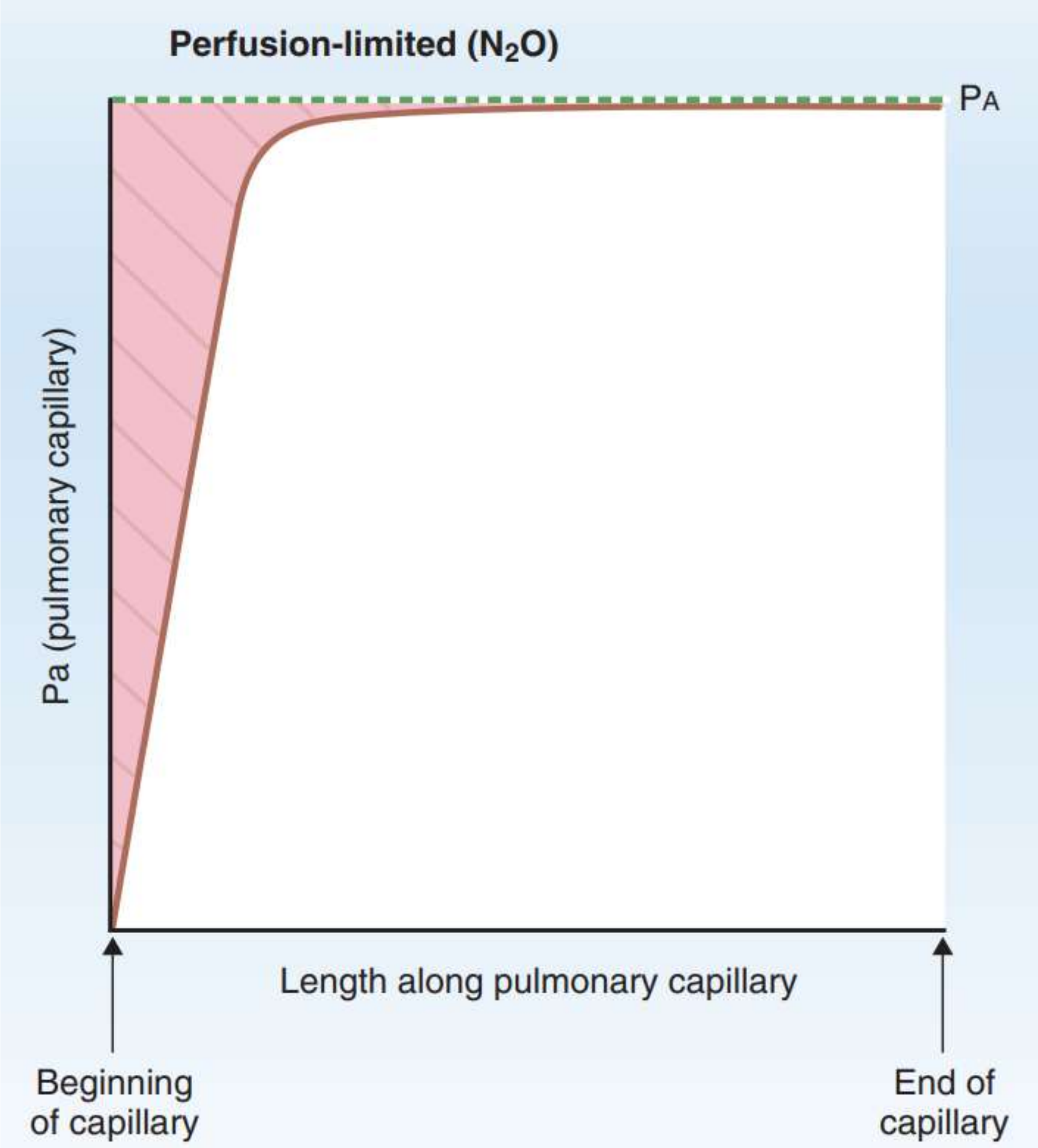
- In these cases, as long as the partial pressure gradient for the gas is maintained, diffusion will continue along the length of the capillary.

Perfusion-limited gas exchange

- The total amount of gas transported across the alveolar-capillary barrier is limited by blood flow (i.e., perfusion) through the pulmonary capillaries.

- In perfusion-limited exchange, the partial pressure gradient is not maintained, and in this case, the only way to increase the amount of gas transported is by increasing blood flow.


Diffusion-limited (CO)
PA
Pa (pulmonary capillary)
Length along pulmonary capillary
Beginning of capillary
End of capillary



Perfusion-limited (N_2O)
PA
Pa (pulmonary capillary)
Length along pulmonary capillary
Beginning of capillary
End of capillary

Perfusion-limited O_2 transport

- Under normal conditions, O_2 transport into pulmonary capillaries is perfusion limited, but under other conditions (e.g., fibrosis or strenuous exercise), it is diffusion limited.

Perfusion-limited O_2 transport

- O_2 (under normal conditions) and CO_2 transport is perfusion-limited.

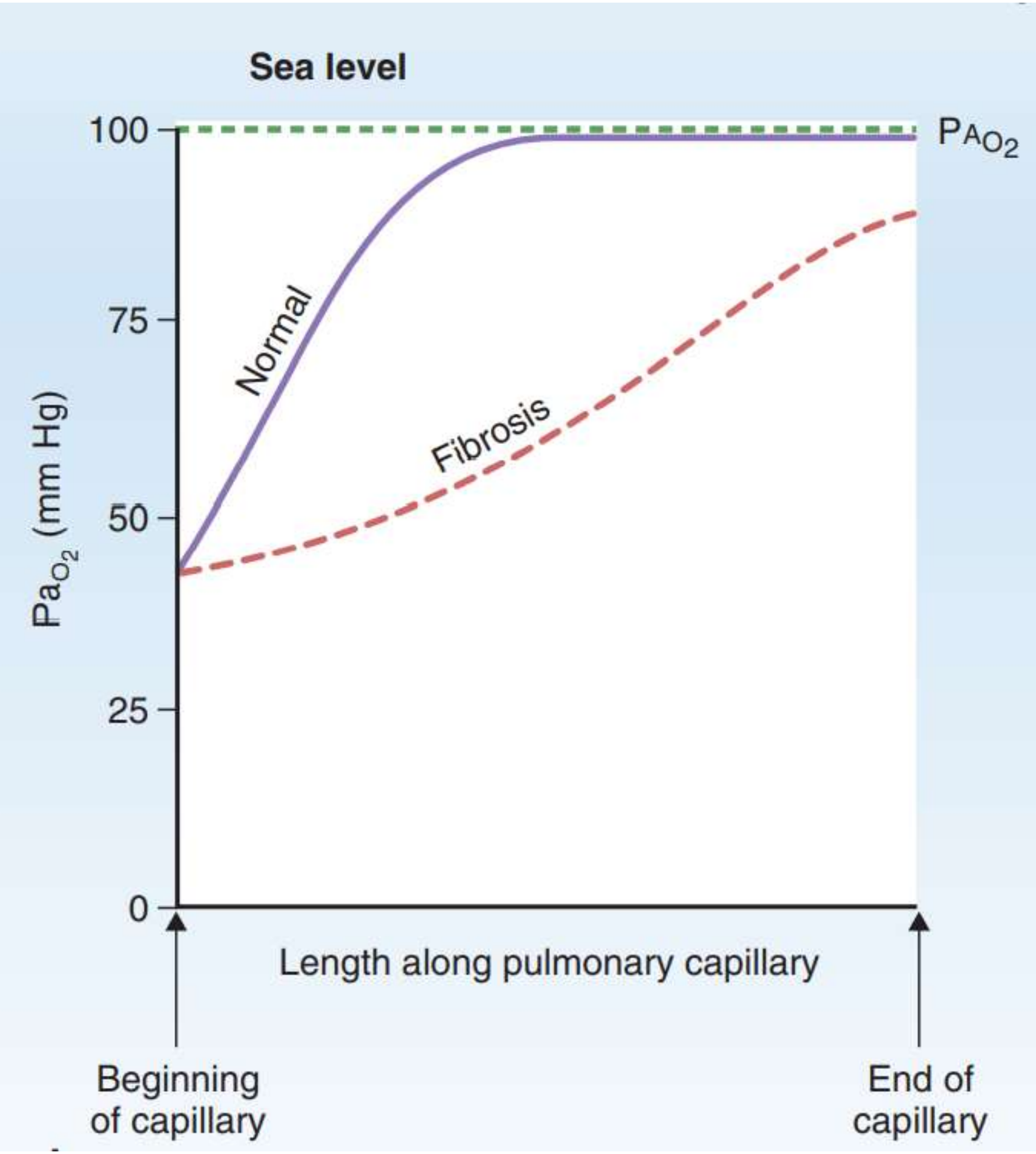
- Pulmonary blood flow determines net O_2 transfer.

- Thus increases in pulmonary blood flow (e.g., during exercise) will increase the total amount of O_2 transported, and decreases in pulmonary blood flow will decrease the total amount transported.

Diffusion-limited O_2 transport

- In certain pathologic conditions (e.g., fibrosis) O_2 transfer becomes diffusion limited.
- For example, in fibrosis the alveolar wall thickens, increasing the diffusion distance for gases and decreasing DL.

O2 diffusion



O_2 transport at high altitude

- At high altitude, barometric pressure is reduced, and with the same fraction of O_2 in inspired air, the partial pressure of O_2 in alveolar gas also will be reduced.

- The partial pressure gradient for O_2 is greatly reduced compared with sea level.

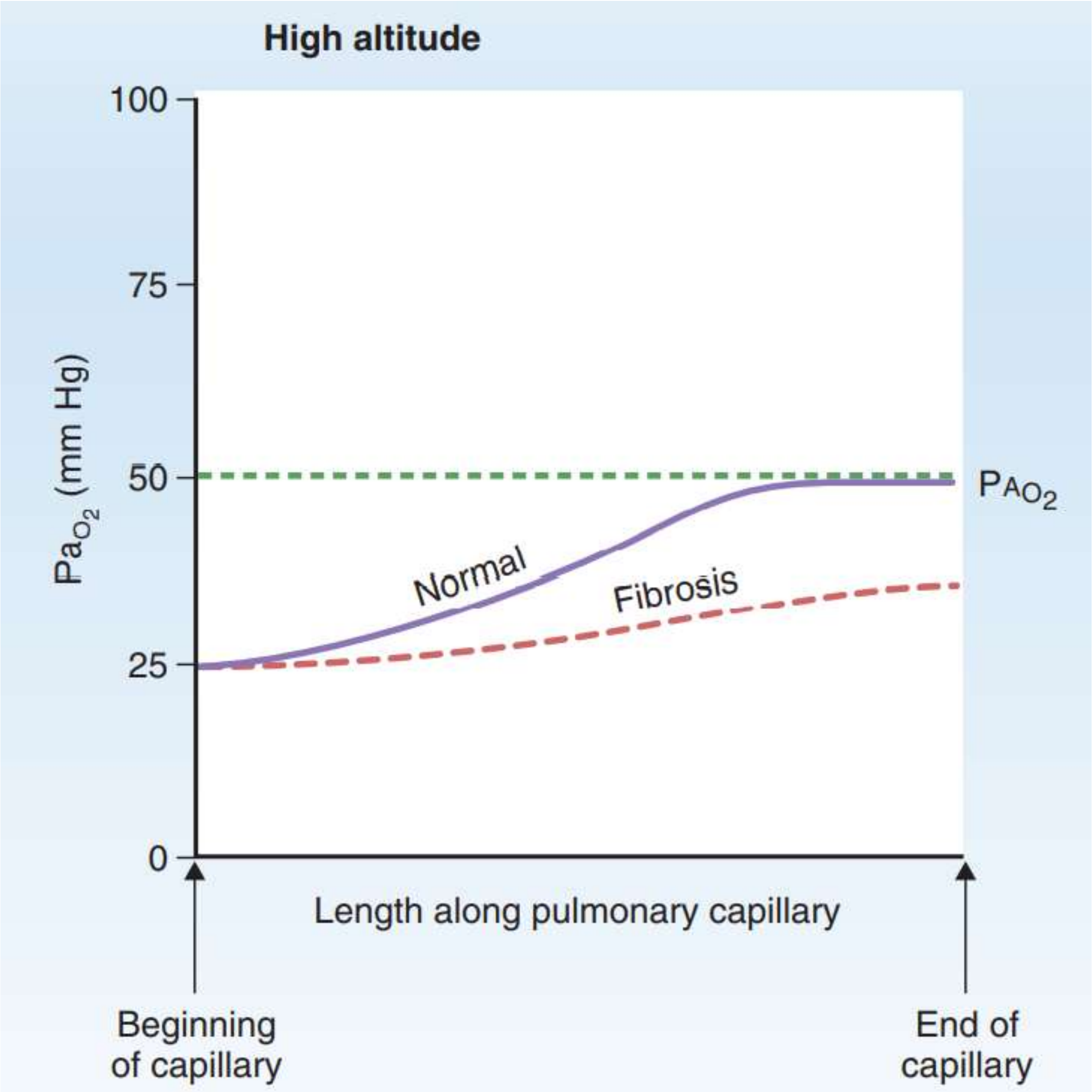
- Equilibration will occur more slowly along the capillary, and complete equilibration will be achieved at a later point along the capillary.

O_2 transport at high altitude

- The slower equilibration of O_2 at high altitude is exaggerated in a person with fibrosis.

- Pulmonary capillary blood does not equilibrate by the end of the capillary, resulting in values for PaO_2 as low as 30 mm Hg, which will seriously impair O_2 delivery to the tissues.

O2 diffusion



Thank you