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Department

Functions of Respiratory Passages And Respiratory Membrane

Learning Outcomes

- Functions of Respiratory Passages.
- Describe the physiologic anatomy of the respiratory membrane and its significance
- Describe the factors that affect the rate of gaseous diffusion through the respiratory membrane
- Describe the diffusing capacity of respiratory membrane for O2 and CO2 at rest and exercise.
- Describe the effect of ventilation/perfusion (V/Q) ratio on alveolar gas concentrations.

Overview of Respiratory Function

- **Gas exchange .**The main function of respiratory system is exchange of gases between atmosphere and body tissues.
- Contributing to the regulation of acid-base balance in the blood
- Enabling vocalization,
- Participating in defense against pathogens and foreign particles in the airways,
- Providing a route for water and heat losses (via the expiration of air that was moistened and Warmed during inspiration
- Enhancing venous return through respiratory pump
- Activating certain plasma proteins as they pass through the respiratory circulation

Functions Of Respiratory Passages

STRUCTURE	FUNCTION
nose / nasal cavity	warms, moistens, & filters air as it is inhaled
pharynx (throat)	passageway for air, leads to trachea
larynx	the voice box, where vocal chords are located
trachea (windpipe)	tube from pharynx to bronchi rings of cartilage provide structure, keeps the windpipe "open" trachea is lined with fine hairs called *cilia* which filter air before it reaches the lungs
bronchi	two branches at the end of the trachea, each lead to a lung
bronchioles	a network of smaller branches leading from the bronchi into the lung tissue & ultimately to air sacs
alveoli	the functional respiratory units in the lung where gases (oxygen & carbon dioxide) are exchanged (enter & exit the blood stream)

THE MUCOCILIARY ESCALATOR

- The mucociliary escalator runs from the bronchi to the larynx, and serves to efficiently clean, moisten, and warm incoming air. It consists of **pseudostratified columnar epithelium** that has tiny hairs called **cilia** on their apical surface. Also included in this epithelial layer are specialized mucus-producing cells called **goblet cells**. Similar to the nasal cavity, the mucus serves to moisten air, while trapping pathogens and debris that is in the air. The mucus sits on top of the cilia, which continually beat upwards, carrying the mucus and any debris that it traps away from the lungs. This cleaning process also serves to eliminate bacteria from the air, thereby protecting the lungs from infection.

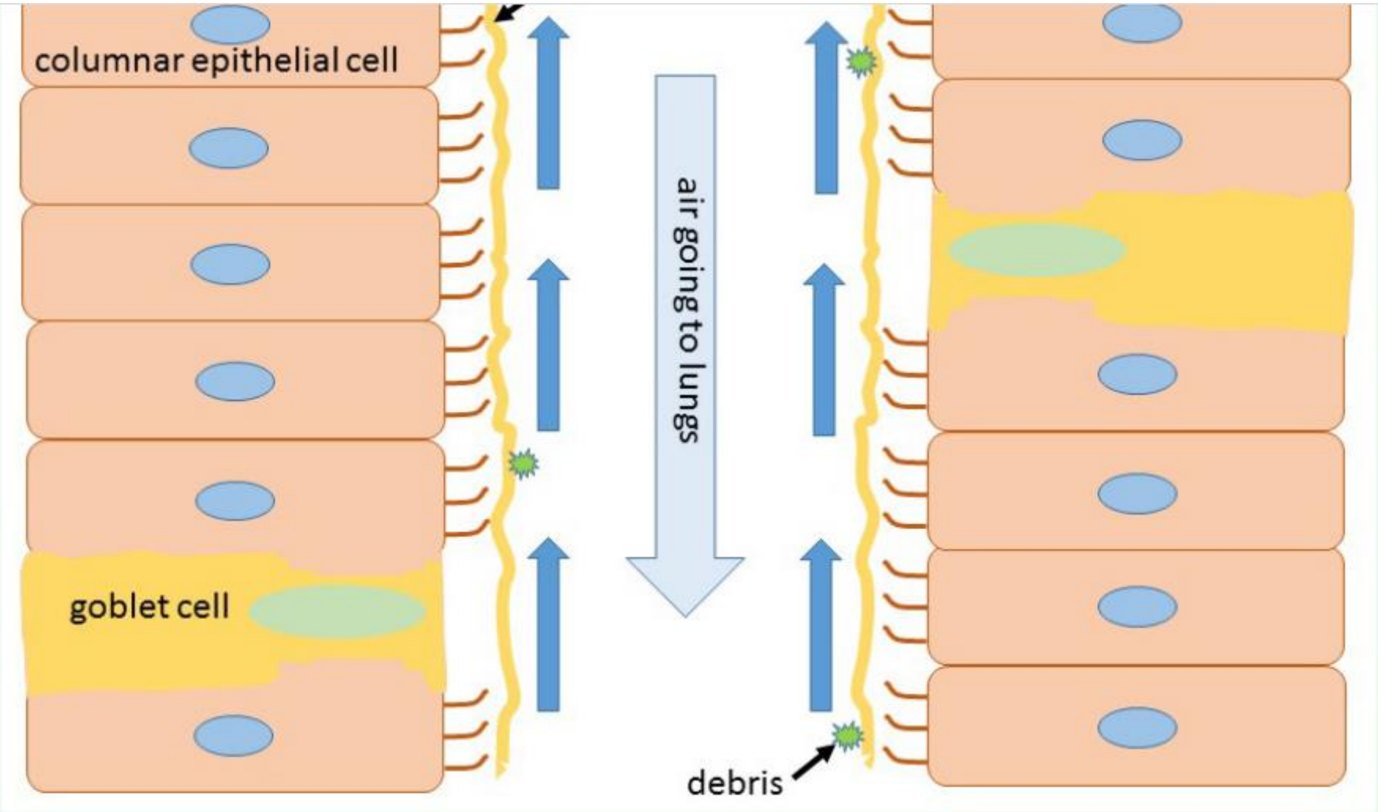


Figure 8. Mucociliary escalator: Debris is trapped in mucus that is made by goblet cells. The mucus and debris are brushed upwards, away from the lungs, thereby ensuring that air is clean prior to entry into the lungs.

DIFFUSION PROCESS IN GAS EXCHANGE

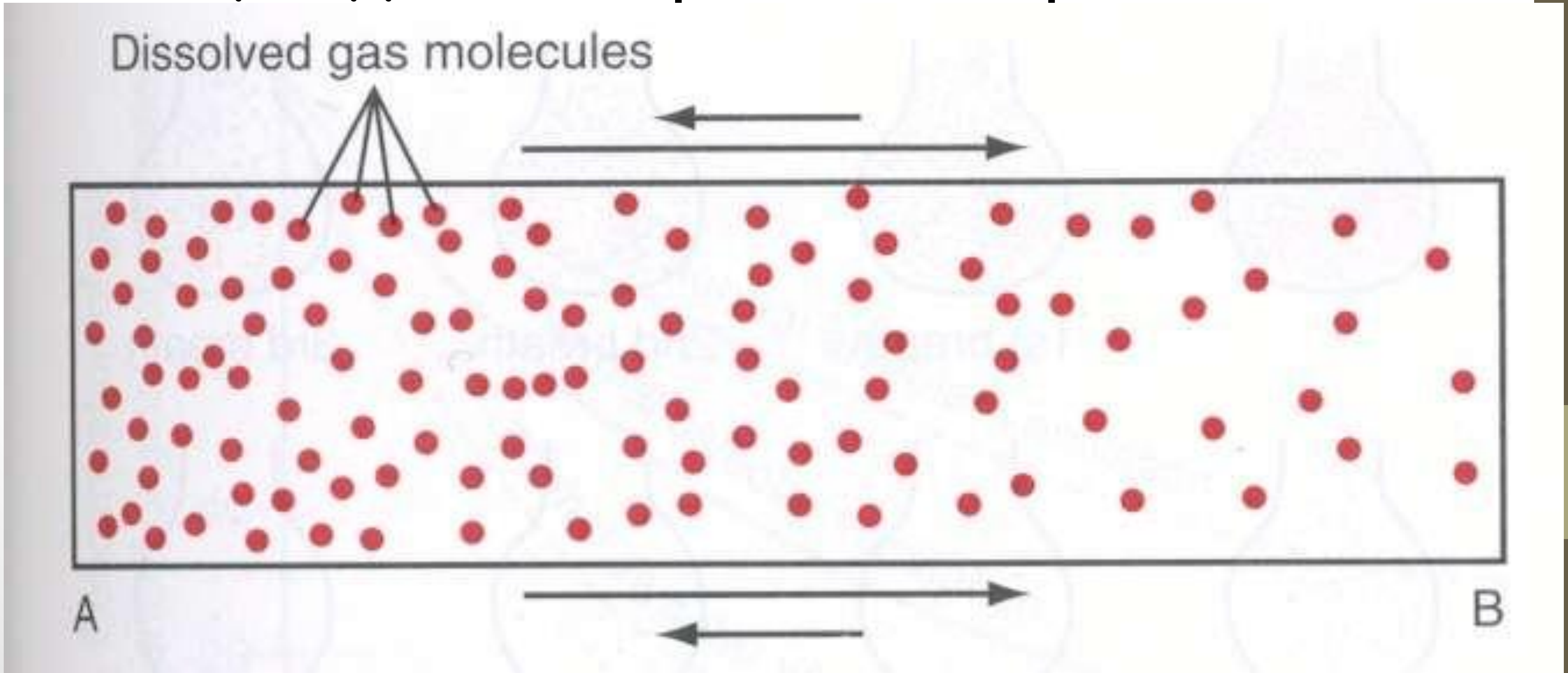
- Random molecular motion of molecules
- Movement in both directions through the membranes & fluids of the respiratory passage ways
- Mechanism & rate of molecule transfer dependant on physics of gas diffusion and partial pressures of gases involved

BASIS OF GAS DIFFUSION

- The gases of respiratory system are simple molecules which are free to move across cell membranes
- These molecules move freely among one another and dissolve easily into fluids or tissues
  - **Kinetic motion provides the energy source for the diffusion process**
  - **Molecules move at high velocity striking into one another and deflecting in new directions**
  - **Molecular movement is continual and random**

NET DIFFUSION OF A GAS

- Movement of a gas in one direction is the effect of a concentration gradient
- Direction of diffusion occurs from areas of high to low concentration
- Rate of diffusion dependant on pressure



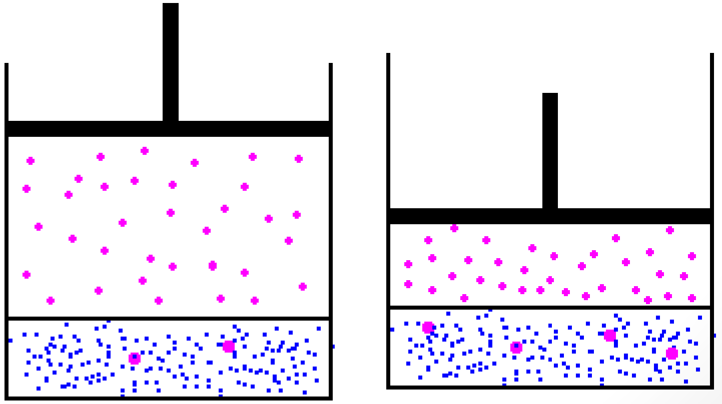
Gas Mixture - Partial Pressures

- Each gas in a mixture contributes to the total pressure in proportion to its concentration
- Pressure is caused by impact of moving molecules against a surface
- The respiratory gases include mainly oxygen, nitrogen & carbon dioxide
- Each gas exerts its own individual pressure on the respiratory wall surface

Composition of Air

- Air is composed mainly of 79% nitrogen & 21% oxygen
- Total pressure of air mixture is 760mmHg
- 1 atmosphere = 760mmHg
- Nitrogen partial pressure
  - 79% of 760 mmHg = 600 mmHg
- Oxygen partial pressure
  - 21% of 760 mmHg = 160 mmHg

- Gases can be dissolved in body fluids & tissues
- Partial pressures of dissolved gases behave similar to gas state
- Factors affecting pressure of dissolved gas
- **Henry's Law** - solubility of a gas in a liquid depends on temperature, the partial pressure of the gas over the liquid, the nature of the solvent and the nature of the gas



SOLUBILITY COEFFICIENT (D)

- Molecules are either attracted or repelled by water
- When dissolved molecules are attracted by water more can be accumulated without building up excess pressure in solution = highly soluble
- Conversely molecules which are repelled by water will dissolve less and have lower concentration = poorly soluble
- Carbon Dioxide is 20 times more soluble than Oxygen

Diffusion between Alveoli & Blood

- Partial pressure of each gas in alveoli force molecules into solution
- Dissolved gases move from blood into alveoli proportional to their partial pressure
- Rate of *net diffusion* is determined by difference of partial pressures (pp)
  - If pp of gas in alveoli > blood then gas moves into blood (Oxygen)
  - If pp of gas in blood > alveoli then gas moves into alveoli (Carbon dioxide)

NET DIFFUSION RATES IN FLUIDS

Factors which affect gas diffusion rates

- Pressure differences
- Gas solubility in fluid
- Area of fluid
- Distance which gas must diffuse
- Molecular weight of gas
- Temperature of fluid (constant in body)

DIFFUSION COEFFICIENT OF THE GAS

- The characteristics of the gas which affect the ability & rate of net diffusion
  - Solubility of gas molecule
  - Molecular weight
- The relative rates at which different gases diffuse are proportional to their diffusion coefficient
- D is directly proportional with solubility
- D is inversely proportional to the square root of the gas' molecular weight

DIFFUSION OF GASES THROUGH TISSUES

- Respiratory gases are highly soluble in lipids (the main component of cell membranes)
- Cell membranes are highly permeable to these gases
  - Rate of gas movement into tissues is limited by diffusion rate of gas through <u>tissue water</u>
  - Movement of gas into & out of tissues = diffusion rate of gas though water

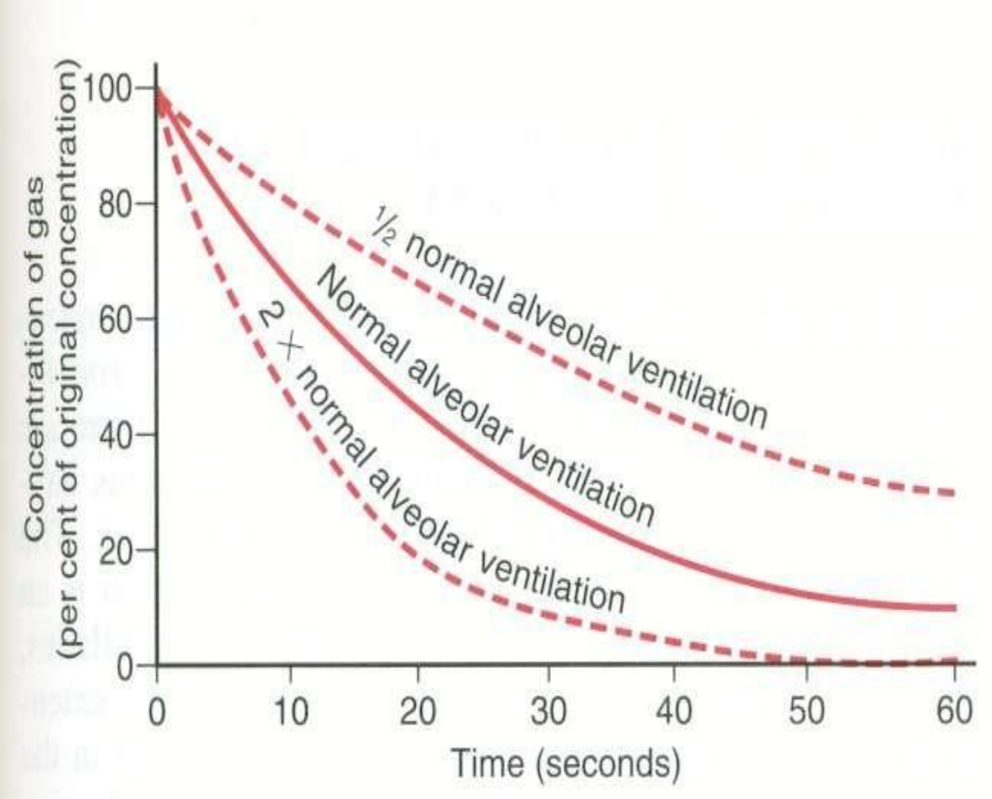
Alveolar Air Composition

- Alveolar air does not have same gas concentrations as atmospheric air composition
- Differences occur because:
  - Alveolar air is partially replaced by atmospheric air during each breath
  - Oxygen constantly absorbed into blood from alveoli
  - Carbon dioxide diffused into alveoli from blood
  - As air enters respiratory passages it becomes humidified diluting the inspired gases partial pressures

RATE OF ALVEOLI GAS REMOVAL

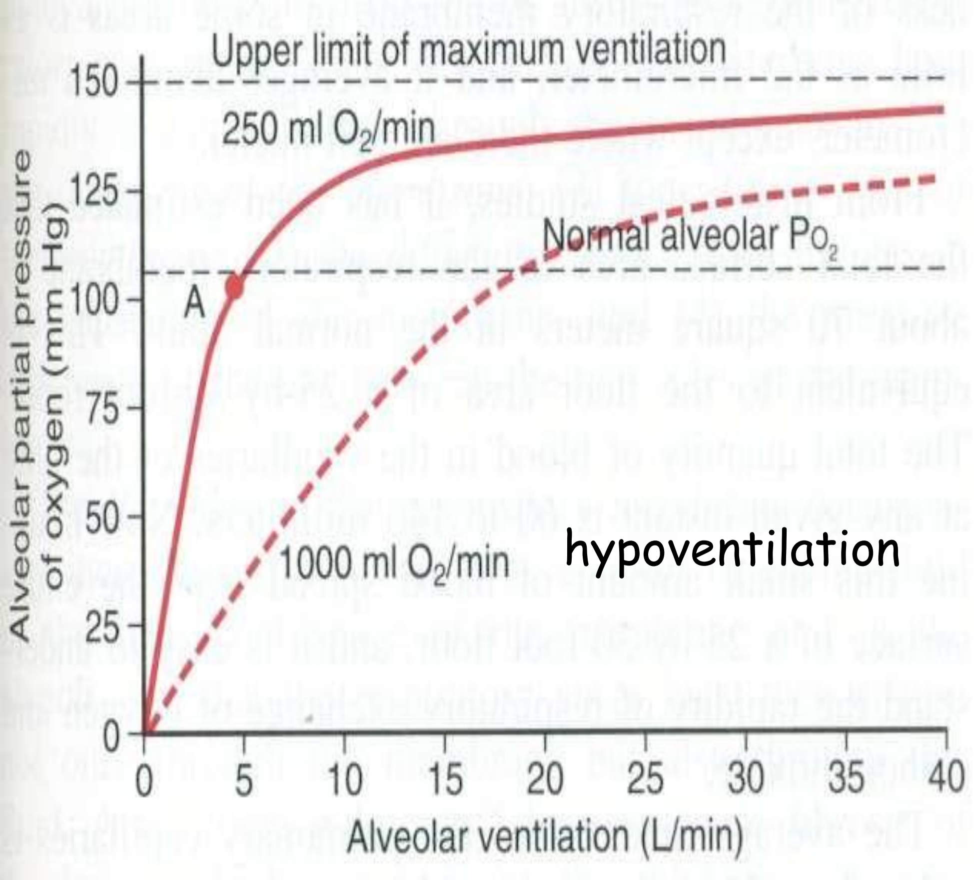
Graph of gas removal

- Normal alveolar ventilation removes ½ of gas in 17 seconds
- Half normal ventilation removes ½ gas in 34 seconds
- Twice normal removes ½ of gas in 8 seconds



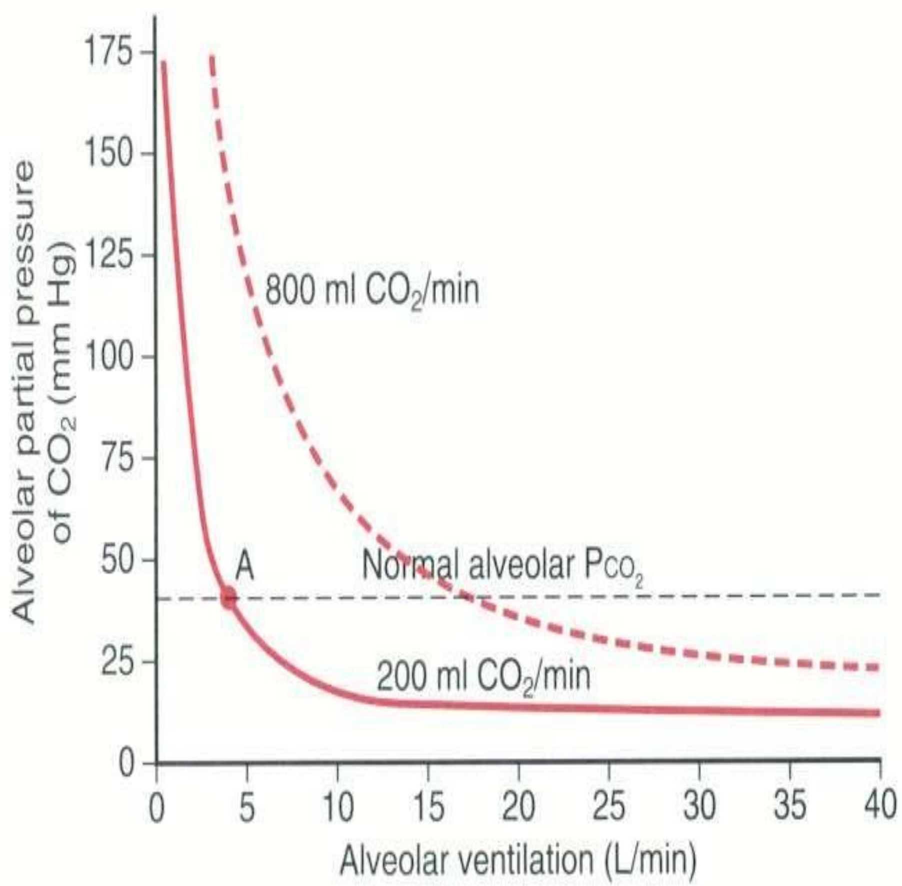
OXYGEN & ALVEOLAR CONCENTRATION

- Oxygen continuously absorbed into blood
- Partial pressure controlled by rate of absorption & ventilation
- Rate of ventilation, oxygen pressure & exercise affect alveolar Po_2
- <u>Normal alveolar PO_2 is 100mmHg</u>



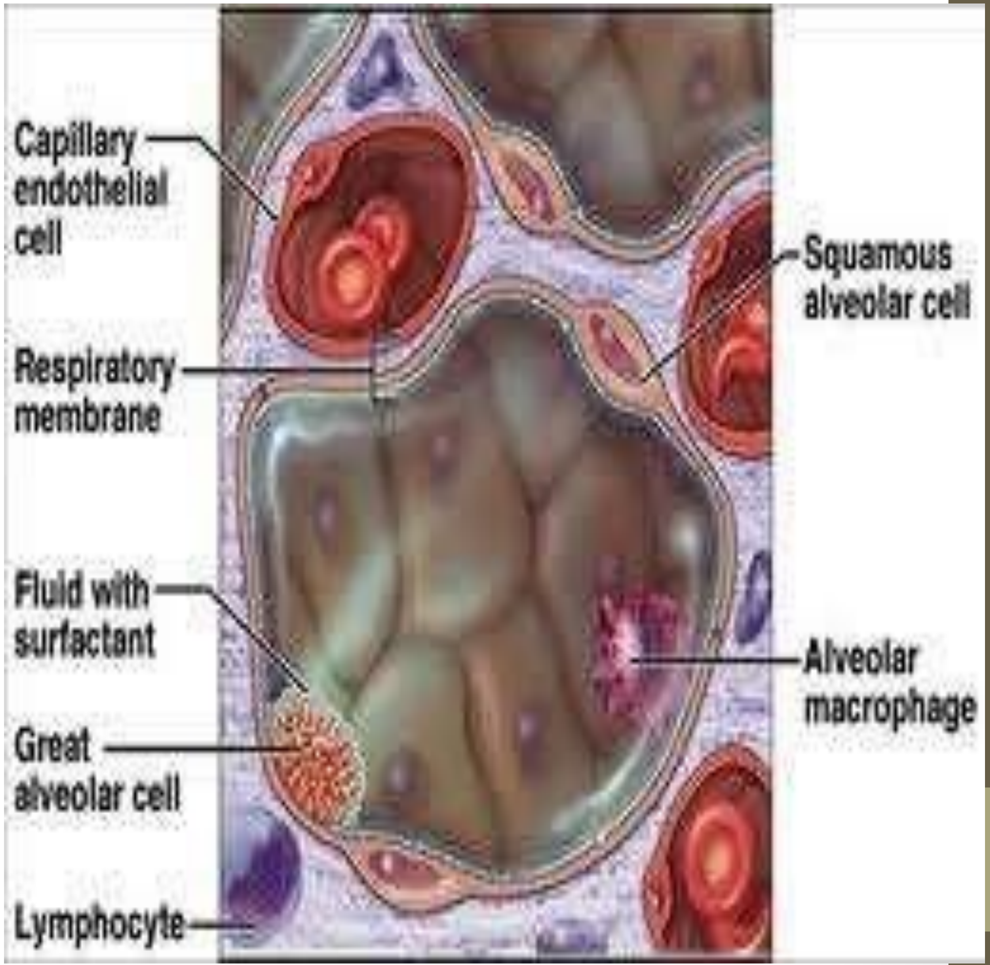
CARBON DIOXIDE IN ALVEOLI

- CO_2 formed in body is discharged into alveoli and removed by ventilation
- <u>Normal alveolar P_{CO_2} is 40 mmHg</u>
- Alveolar P_{CO_2} increases in proportion to CO_2 excretion
- P_{CO_2} decreases in inverse to alveolar ventilation



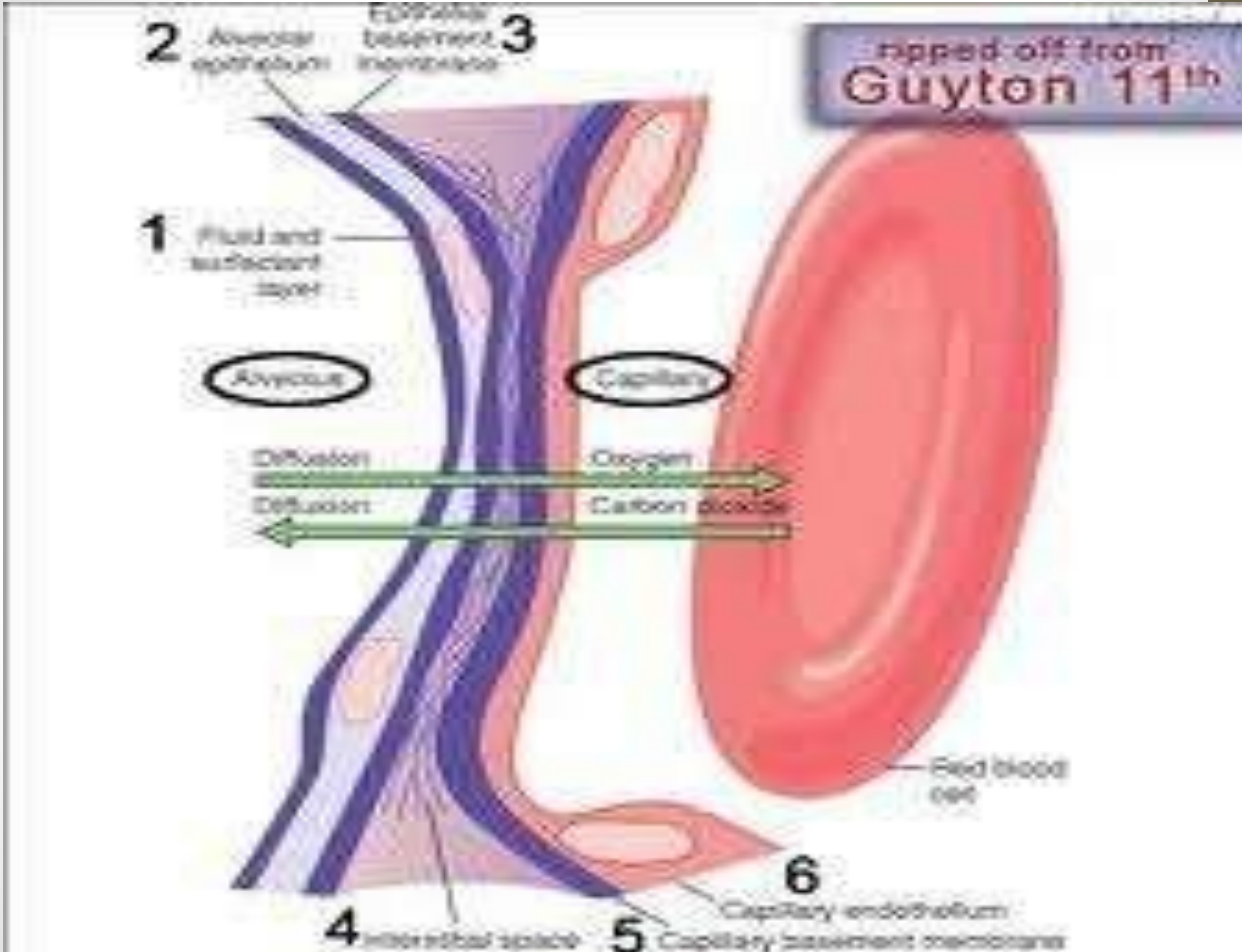
RESPIRATORY MEMBRANE (ALVEOLOCAPILLARY MEMBRANE)

- Gases diffuse from alveoli to blood or vice versa in pulmonary capillaries across thin respiratory membrane in respiratory zone.



FUNCTIONAL ANATOMY

- Layer of fluid and surfactant
- Pulmonary epithelium
- Basement membrane (epithelial and endothelial)
- Thin interstitial space
- Capillary basement membrane
- Capillary endothelium


ripped off from
Guyton 11th
2 Alveolar epithelium
Epithelial basement membrane 3
1 Fluid and surfactant layer
Alveolus
Capillary
Diffusion
Oxygen
Diffusion
Carbon dioxide
Red blood cell
6
Capillary endothelium
4 Interstitial space
5 Capillary basement membrane

Respiratory Membrane & Diffusion

- Multiple different layers
  - Overall thickness @ 0.6 micrometers
  - Total surface area 70 square meters
- Minimal transfer time & distance through plasma
- Rapid diffusion rates for respiratory gases

FICK'S LAW

- Diff. = (A * Δpp * D) / T
- Diff. is diffusion of gas through a tissue membrane
- A is cross sectional area of membrane
- Δpp is the driving pressure (partial pressure difference)
- D is gas coefficient
- T is tissue thickness or length through membrane

RATE OF DIFFUSION & RESPIRATORY MEMBRANE

Factors that affect rate of gas diffusion through the respiratory membrane

1. **Thickness of respiratory membrane**
   - Rate of diffusion inversely proportional to membrane thickness
   - Increasing thickness by 2 – 3 times interferes significantly with normal respiratory exchange
   - Edema fluid & fibrosis increase thickness

2. Surface area of respiratory membrane

- Decreases of surface area to $\frac{1}{4}$ normal impedes gas exchange significantly
- Emphysema – dissolution of many alveolar walls to coalesce alveoli into larger chambers (surface area decreased as much as 5-fold)
- Removal of lung tissue during surgery effects gas exchange

3.Transfer of gas through membrane depends on the Diffusion coefficient (D)

- Solubility and molecular weight of gas determine D
- CO_2 diffuses 20 times faster than Oxygen
- Oxygen diffuses twice as rapidly as nitrogen

4.Pressure difference across the respiratory membrane

- Difference in partial pressures of gas in alveoli & pulmonary blood
- Measure of net tendency for gas molecules to move through the membrane
- Diffusion occurs across the membrane down the pressure gradient, simple diffusion

DIFFUSING CAPACITY

'The volume of a gas that will diffuse through the respiratory membrane each minute for a pressure difference of 1 mmHg'

- The ability to exchange gas between alveoli & pulmonary blood expressed in quantitative terms
- The factors which affect diffusion through the respiratory membrane can affect the **diffusion capacity**

Diffusing Capacity for Oxygen

- The diffusing capacity for O_2 is 21 ml/min/mmHg
- The mean oxygen pressure difference across the respiratory membrane is 11 mmHg
- The pressure difference multiplied by the diffusing capacity = the total quantity of O_2 diffusing across the membrane per minute

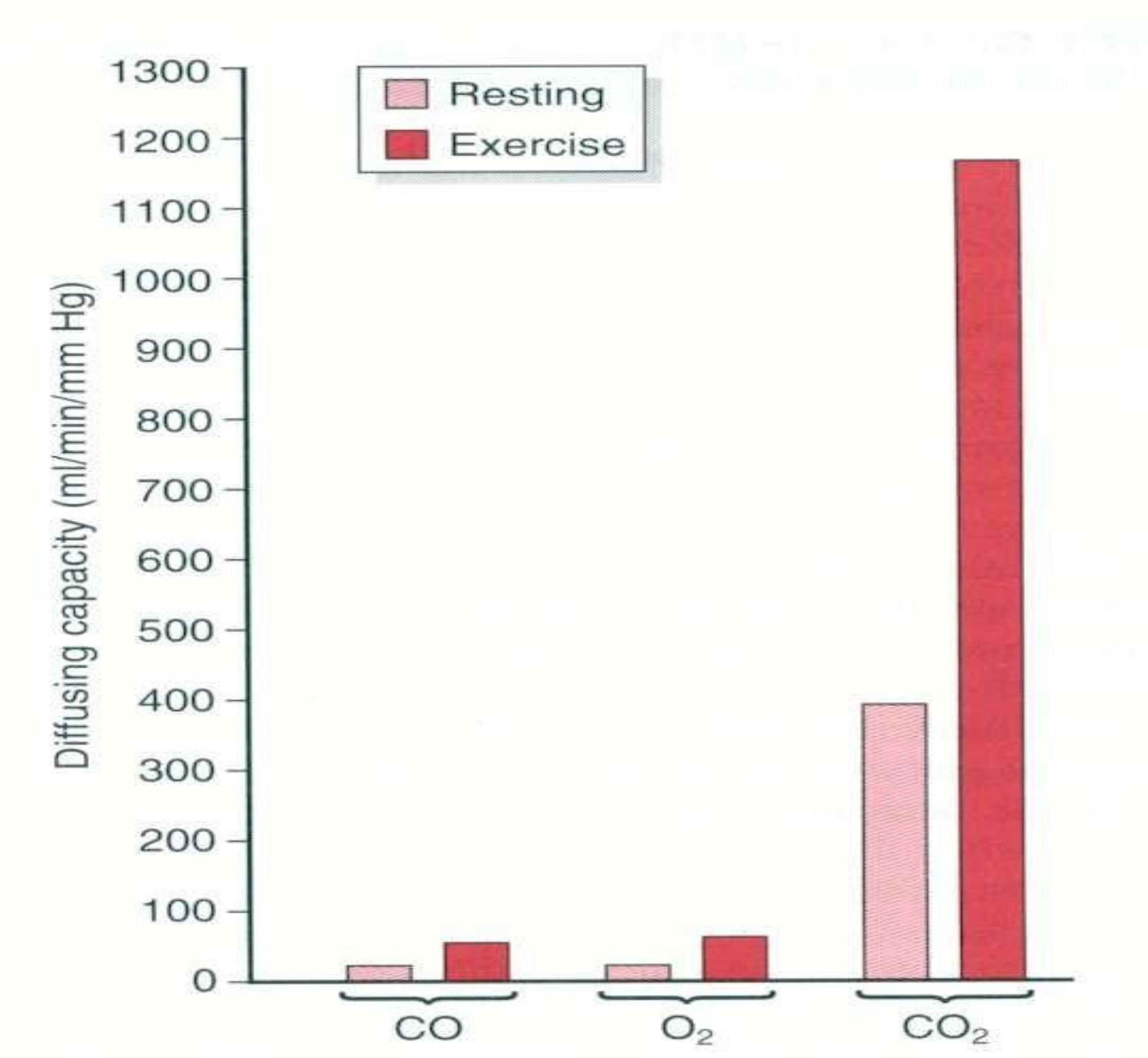
Oxygen Diffusion Capacity during Exercise

- Exercise increases pulmonary blood flow & alveolar ventilation
- Oxygenation of blood is increased
- Diffusing capacity increases three-fold to max @ 65 ml/min/mmHg
- Increase caused by several factors:
  - Recruitment of capillary fields (increased surface area of blood for O2 to diffuse)
  - Better ventilation/perfusion match with blood

Carbon Dioxide Diffusing Capacity

- CO_2 diffuses very rapidly through respiratory membrane
- Minimal concentration differences between blood & alveoli
- Technically too difficult to measure CO_2 diffusing capacity – so estimates based on diffusion coefficient
- Diffusing capacity of CO_2
  - Resting conditions – 400 ml/min/mmHg
  - During exercise – 1200 ml/min/mmHg

DIFFUSING CAPACITY RATES



V/Q Ratio & Alveolar Gas Concentration

- Highly quantitative concept of imbalance between alveolar ventilation & blood flow
  - When alveolar ventilation and blood flow is normal V/Q is normal
  - When ventilation = zero but perfusion present then V/Q is zero
  - If ventilation present but no perfusion then V/Q = infinity

- If V/Q ratio is either zero or infinity there is no exchange of gases

V/Q EQUALS ZERO

- When V/Q = Zero there is blood flow but no alveolar ventilation (complete airway obstruction)
- Gases diffuse between blood & alveolar air
- Air in alveoli reaches equilibrium with deoxygenated blood returning to lungs in pulmonary arteries
- In normal deoxygenated blood - the PO_2 is 40 mmHg & PCO_2 is 45 mmHg

V/Q Equals Infinity

- V/Q = infinity when there is alveolar ventilation but no blood flow (pulmonary artery obstruction)
- Alveolar air becomes equal with humidified inspired air
  - No loss of oxygen into blood
  - No gain of CO_2 from blood
- Alveolar gas partial pressures
  - PO_2 is 150 mmHg
  - PCO_2 is 0 mmHg

NORMAL V/Q & GAS EXCHANGE

- When ventilation & capillary blood flow are normal then gas exchange is optimal
- Alveolar gas partial pressures balanced between pulmonary air & blood

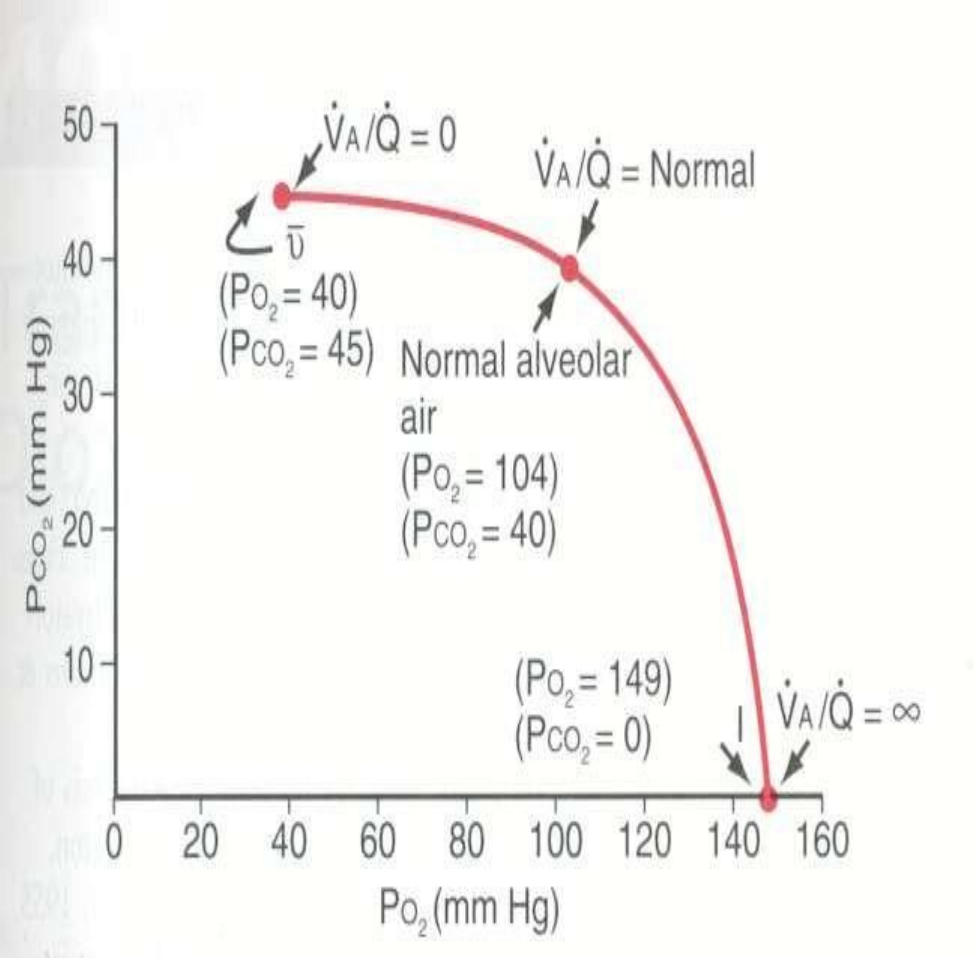
Inspired air

  - (PO_2 150 mmHg / PCO_2 0 mmHg)

Venous blood

  - (PO_2 40 mmHg / PCO_2 45 mmHg)

- Normal alveolar partial pressures
  - Alveolar PO_2 is @ 100 mmHg
  - Alveolar PCO_2 averages @ 40 mmHg



Thank You