# DEAD SPACE AND ALVEOLAR VENTILATION

Dr Afsheen Mahmood Noor

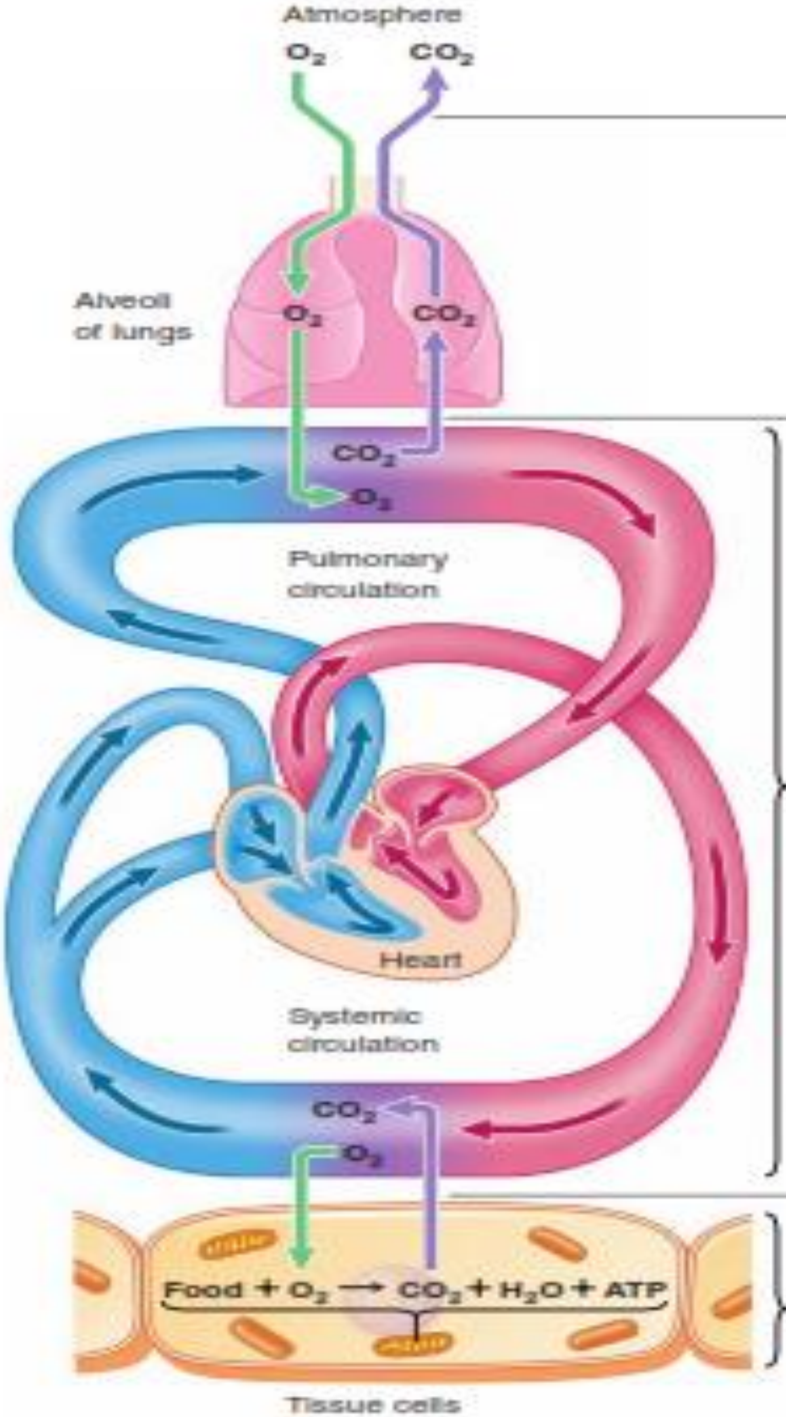
1. Define respiration
2. Compare between the internal and external respiration
3. Enlist the steps of external respiration accomplished by the respiratory system and those carried out by the circulatory system
4. State the functions of Type I alveolar cells, Type II alveolar cells, and alveolar macrophages
5. Describe the forces that keep the alveoli open and those that promote alveolar collapse.

# Respiration

- Respiration involves the sum of the processes that accomplish ongoing passive from the atmosphere to the tissues to support cell metabolism and the continual passive movement of metabolically produced $CO_2$ movement of $O_2$ from the tissues to the atmosphere.

# External Respiration

- The term **external respiration** refers to the entire sequence of events in exchange of $O_2$ and $CO_2$ between the external environment and tissue cells.
- External respiration has got 4 steps




## STEPS OF EXTERNAL RESPIRATION

1 Ventilation or gas exchange between the atmosphere and air sacs (alveoli) in the lungs

2 Exchange of $O_2$ and $CO_2$ between air in the alveoli and the blood in the pulmonary capillaries

3 Transport of $O_2$ and $CO_2$ by the blood between the lungs and the tissues

4 Exchange of $O_2$ and $CO_2$ between the blood in the systemic capillaries and the tissue cells

## CELLULAR RESPIRATION

# Internal Respiration or Cellular Respiration

- Cellular Respiration, The term **cellular respiration refers** to the intracellular metabolic processes carried out within the mitochondria, which use $O_2$ and produce $CO_2$ while deriving energy from nutrients.

- **Cellular respiration refers collectively to the intracellular** reactions in which energy-rich molecules are broken down to form ATP, using $O_2$ and producing carbon dioxide ($CO_2$) in the process.

# INTERNAL RESPIRATION
VERSUS
# EXTERNAL RESPIRATION

| Internal Respiration | External Respiration |
| --- | --- |
| Internal respiration refers to the gas exchange across the respiratory membrane in the metabolizing tissues | External respiration refers to the gas exchange across the respiratory membrane of lungs |
| Oxygen diffuses out from the blood into tissue | Oxygen diffuses from alveolar air into the blood |
| Partial pressure of Oxygen in the blood is reduced from 100 mmHg to 40 mmHg | Partial pressure of Oxygen in the blood is increased from 40 mmHg to 100 mmHg |
| Carbon dioxide diffuses into the blood from the tissue | Carbon dioxide diffuses out from the blood into the alveolar air |
| Partial Pressure of Carbon Dioxide in the blood is increased from 40 mmHg to 45 mmHg | Partial Pressure of Carbon Dioxide in the blood is reduced from 45 mmHg to 40 mmHg |
| Only correlates with the internal environment | Correlates with both internal and external environment |

# Alveoli

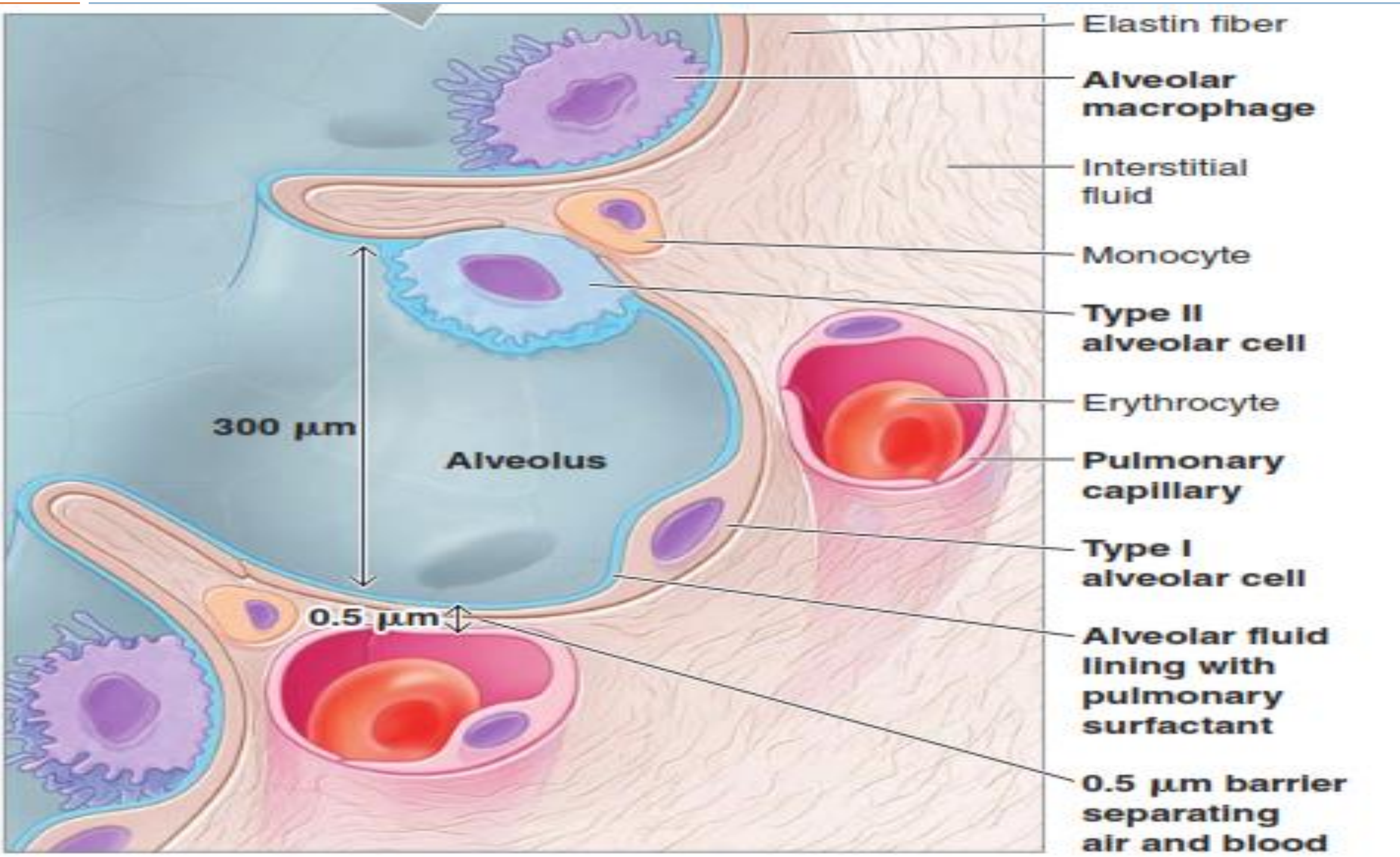
- Clustered at the end of each bronchi are small air sacs called **“Alveoli”**
- Clusters of thin-walled grape-like sacs.
- Tiny air sacs where gaseous exchange between air and blood takes place.
- ALVEOLAR WALL

  The alveolar wall consists of two types of cells

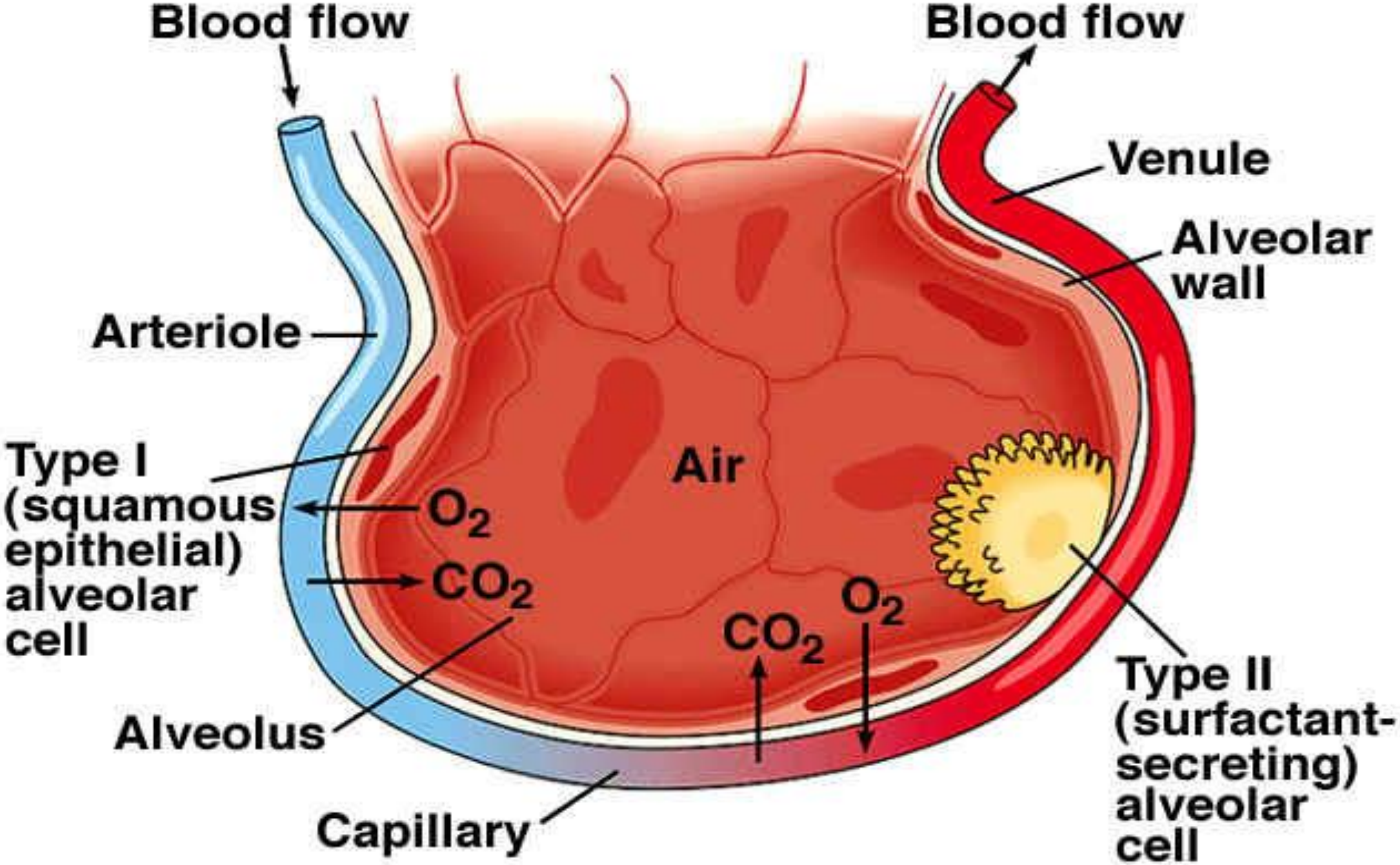
# Alveolar Cells

- Type I alveolar cells are the primary lining cells.
- Type II alveolar cells / granular pneumocytes which secrete surfactant.
- Alveolar macrophages, lymphocytes, plasma cells, mast cells and APUD (Amine precursor uptake and Decarboxylation) cells are also present in the alveoli.

# Alveolus and surrounding pulmonary capillaries



# Alveolus—Gas Exchange



# Type I Alveolar cell:

- Covers majority of alveolar membrane, about 95%
- Relatively large extremely fattened cells and make up most of the alveolar walls.
- This is a single layer of cells.
- Squamous type.
- Allows for rapid gas diffusion between alveolar cells and blood stream.

# Type II Alveolar cells:

- Fewer in number, about 5%
- They are of cuboidal type.
- Produce surfactant.
- Repair alveolar epithelium when type 1 cells are damaged.
- They secrete surfactant, phospholipoprotein, that facilitates lung expansion.

# Alveolar Macrophages

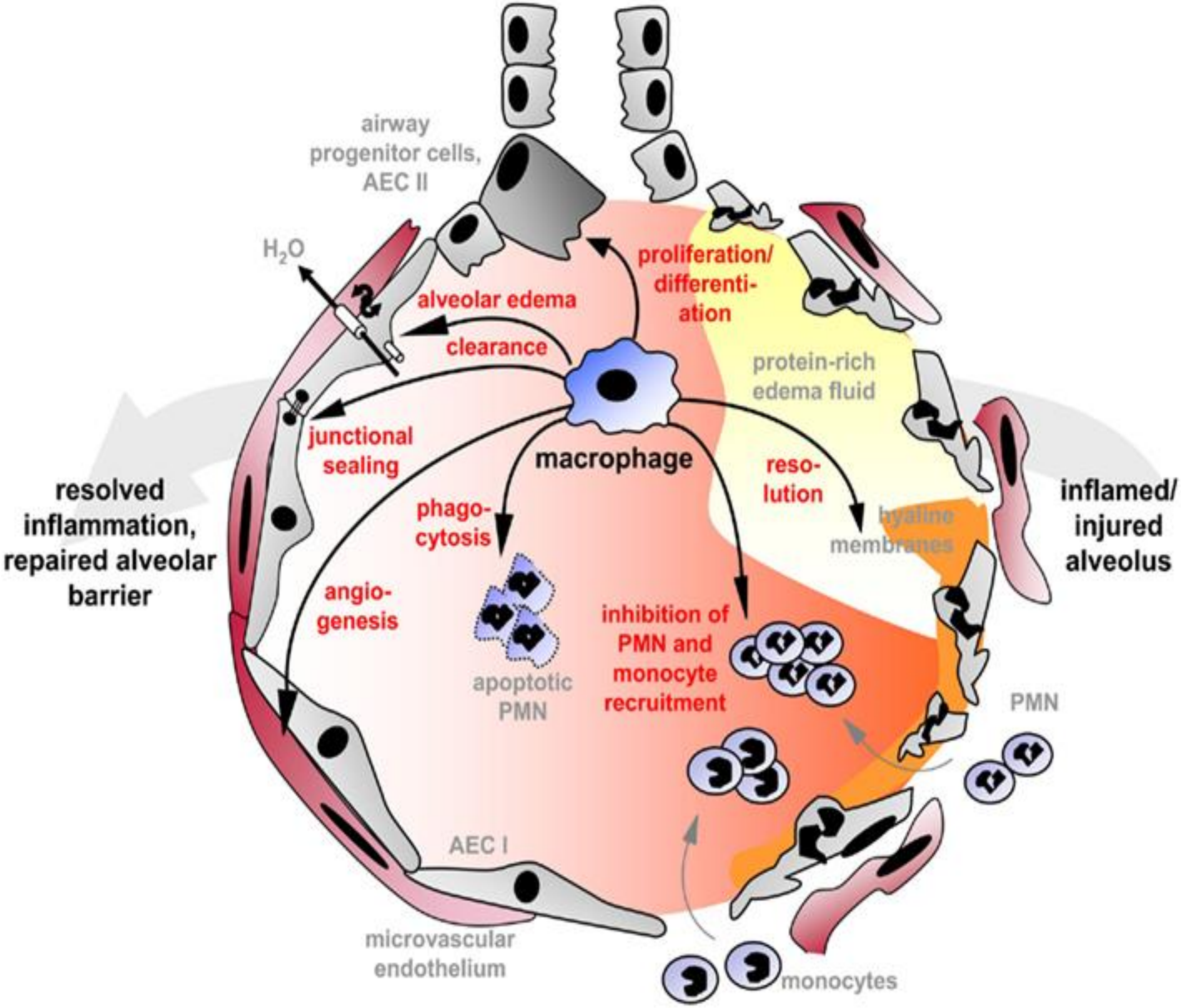
- They are mononuclear phagocytes found in the alveoli of the lungs.
- Are the primary phagocytes of the innate immune system clearing the air spaces of:
  - Infectious,
  - Toxic or
  - Allergic particles that have invaded the mechanical defenses of the respiratory tract such as the
    - Nasal passages,
    - Glottis and the
    - Mucociliary transport system

# Alveolar Macrophages….cont.

- They perform their function by secretion of:
  - Oxygen metabolites
  - Lysozymes,
  - Antimicrobial peptides,
  - Proteases, and
  - through process of phagocytosis
- By intracellular killing, alveolar macrophages can eliminate the small inoculum of typical microbes which are aspirated daily in the normal host.

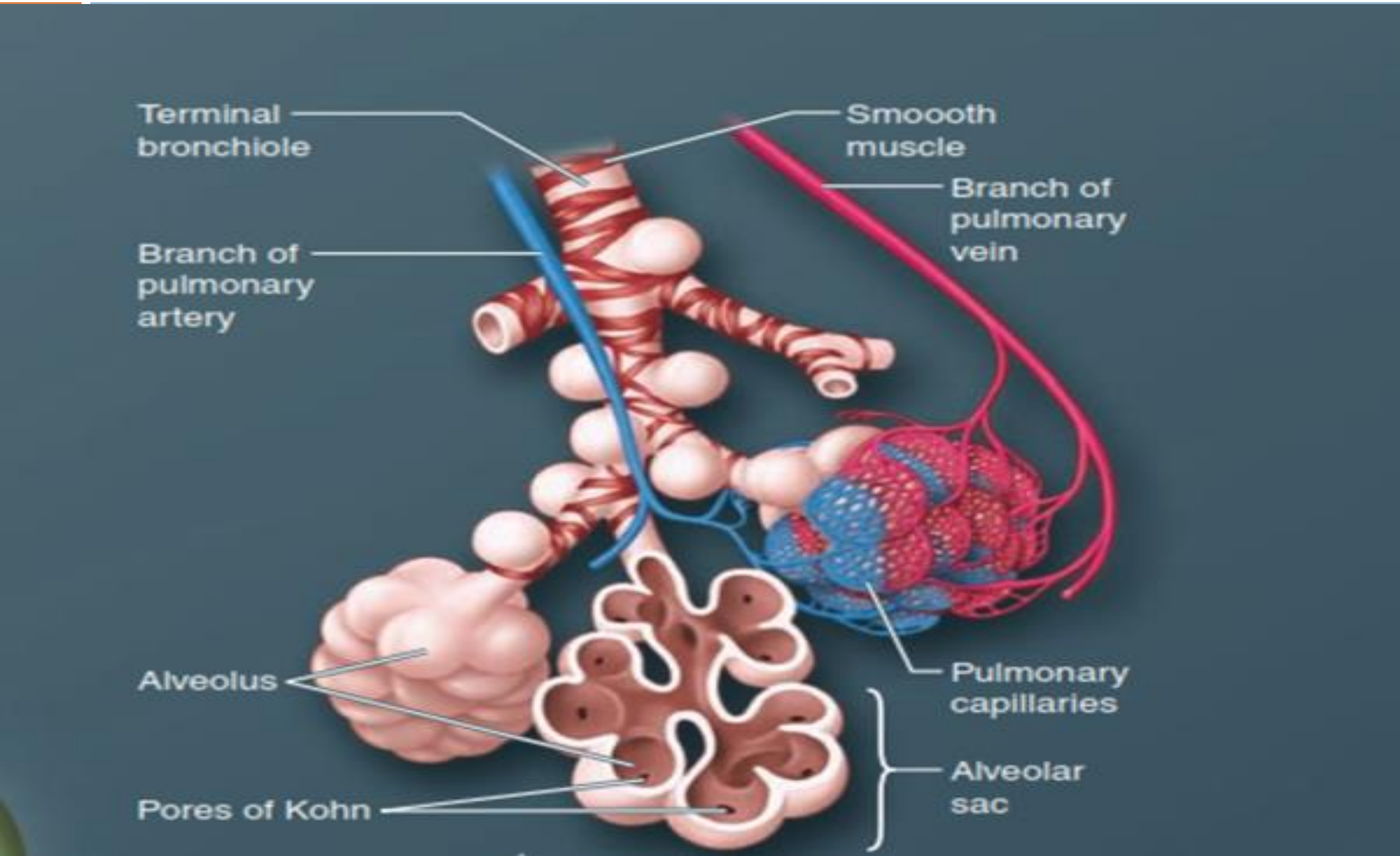
# PORES OF KOHN

- Between adjacent walls of alveoli are present pores of kohn.
- They permit air flow between adjacent alveoli.

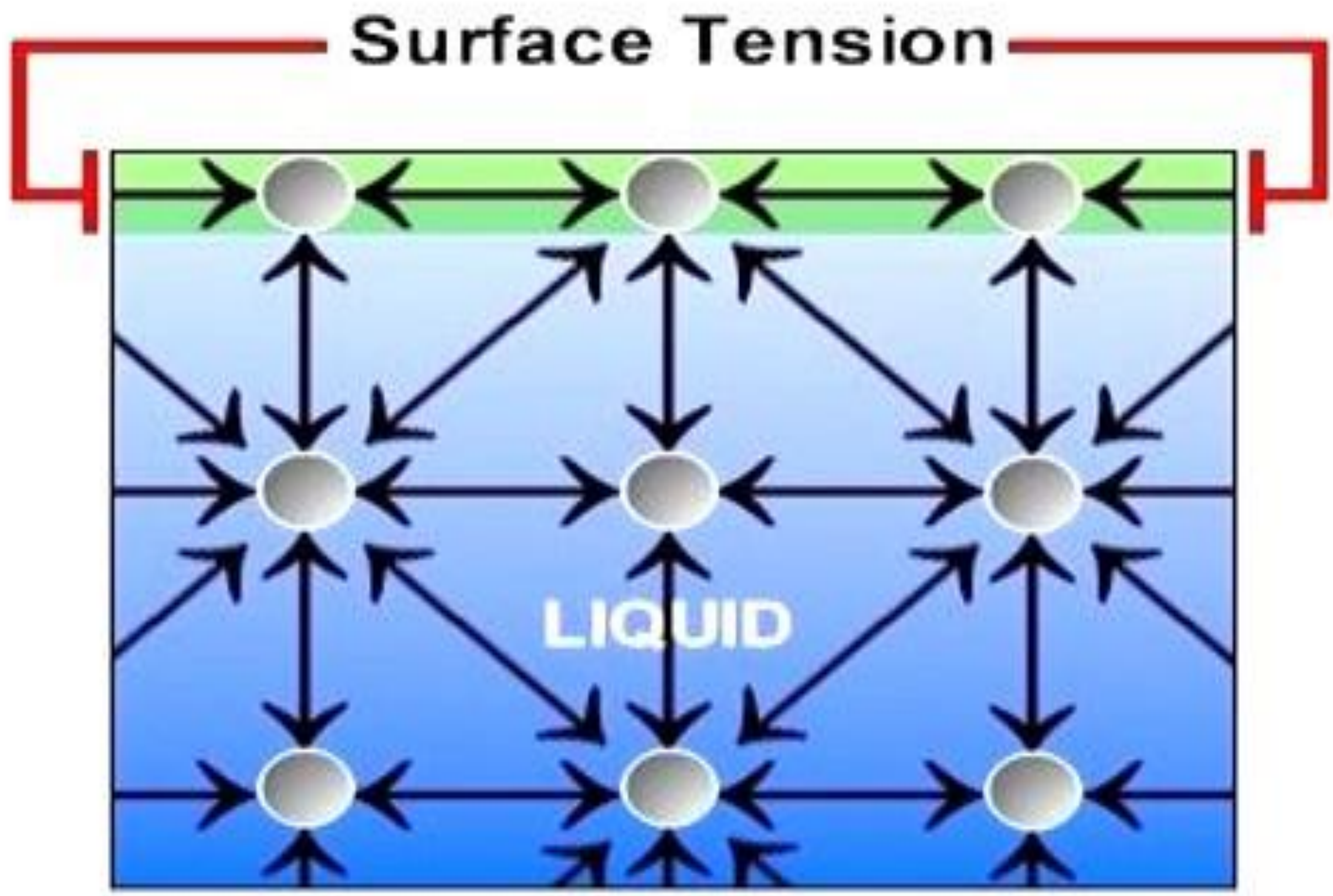



Alveolar Macrophage

# Enlargement of alveoli (air sacs) at terminal ends of airways



Intermolecular attractions between water molecules



# Pulmonary Surfactant

- Synthesized by type II alveolar cells.
- constitute about 10% of the surface area of the alveoli.
- **Reduces surface tension (prevents alveolar collapse during expiration)**
- Prevents bacterial invasion.
- Cleans alveoli surface.
- Composed of surfactant apoprotein + phospholipids (dipalmitoylphosphatidylcholine) + calcium ions

# Mechanism of action of Surfactant

- The dipalmitoyl phosphatidylcholine and several less important phospholipids are responsible for reducing the surface tension
- They do this by not dissolving uniformly in the fluid lining the alveolar surface.
- Instead, part of the molecule dissolves while the remainder spreads over the surface of the water in the alveoli.
- This surface has from one-twelfth to one-half the surface tension of a pure water surface.

# Surface tension…. Cont.

- In quantitative terms, the surface tension of different water fluids is approximately the following:

1. pure water. 72 dynes/cm;

2.normal fluids lining the alveoli but without surfactant. 50 dynes/cm;

3. normal fluids lining the alveoli and *with* normal amounts of surfactant included, between 5 and 30 dynes/cm.

# Pressure in Occluded Alveoli Caused by Surface Tension

- If the air passages leading from the alveoli of the lungs are blocked, the surface tension in the alveoli tends to collapse the alveoli.
- This creates positive pressure in the alveoli, attempting to push the air out.
- The amount of pressure generated in this way in an alveolus can be calculated from the following formula:

$$\text{Pressure} = \frac{2 \times \text{Surface tension}}{\text{Radius of alveolus}}$$

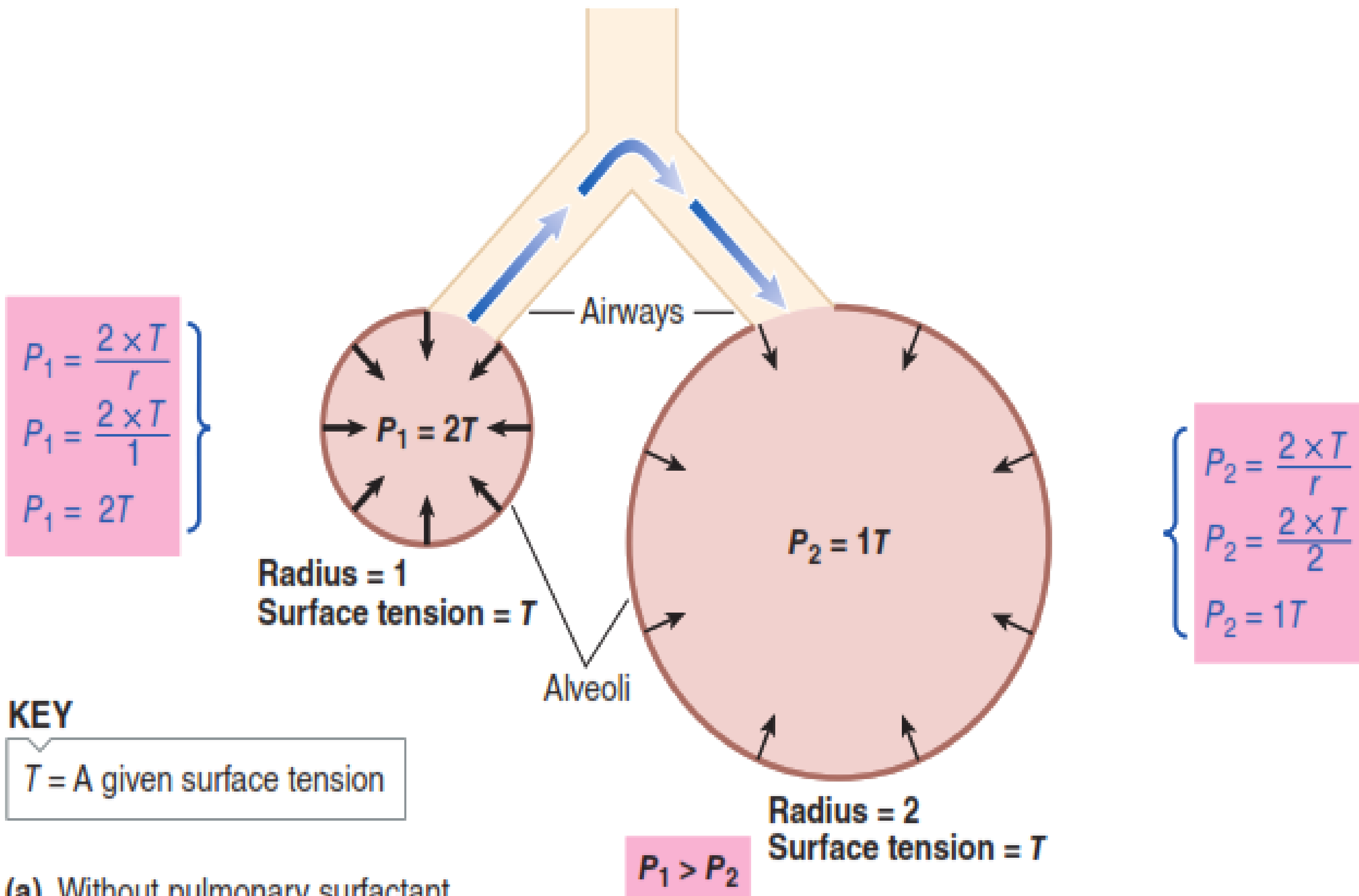
# Pressure within the Alveoli

- For the average-sized alveolus with a radius of about 100 micrometers lined with *normal surfactant*, the pressure is about 4 cm of water pressure (3 mm Hg).

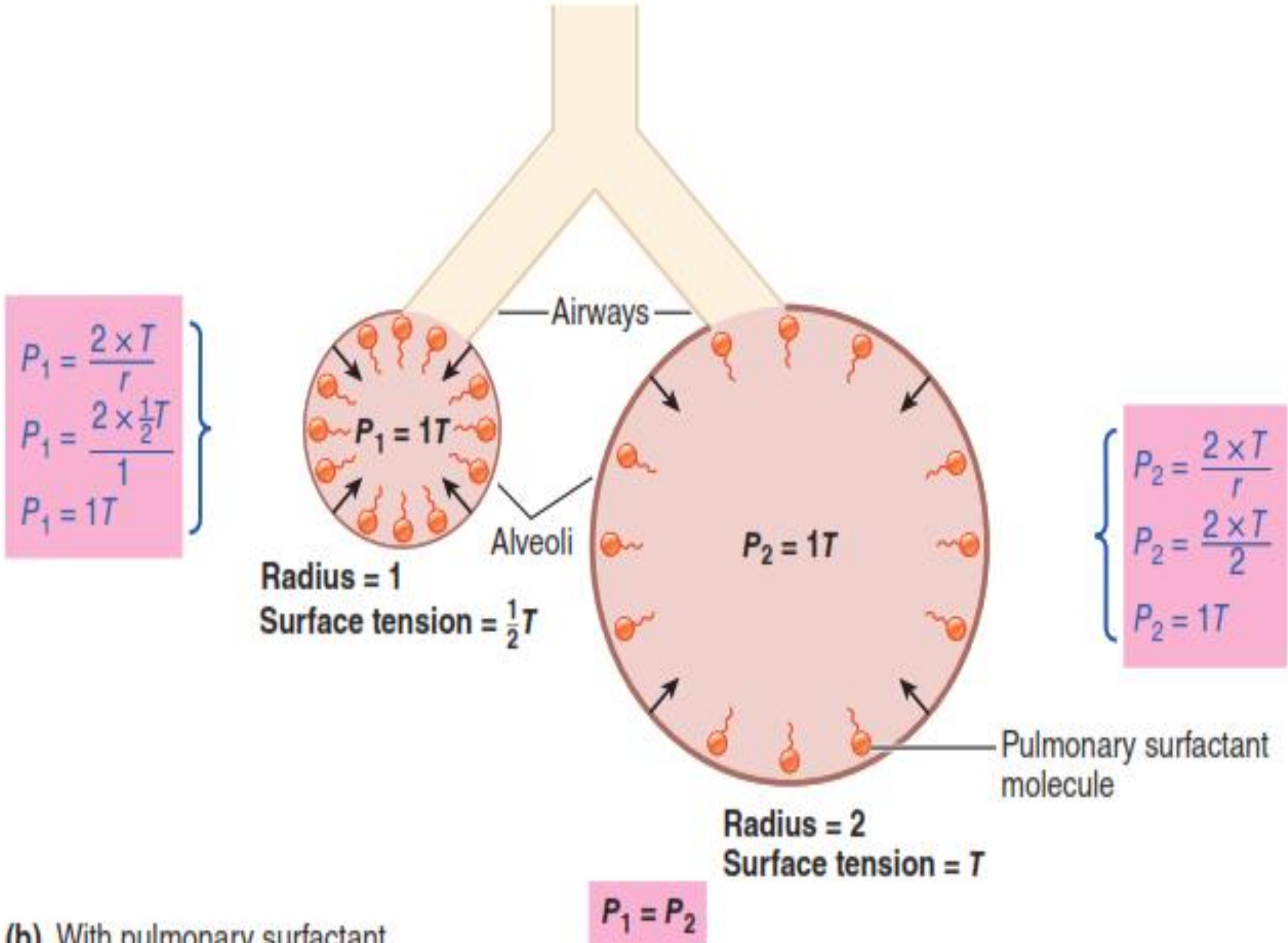
- If the alveoli were lined with pure water without any surfactant, the pressure would be about 18 cm of water pressure, 4.5 times as great.

**Law of LaPlace:**

Magnitude of inward-directed pressure ($P$) in a bubble (alveolus) = $\dfrac{2 \times \text{Surface tension } (T)}{\text{Radius } (r) \text{ of bubble (alveolus)}}$




**(a)** Without pulmonary surfactant




**(b)** With pulmonary surfactant

# Effect of Alveolar Radius on the Pressure Caused by Surface Tension

- The pressure generated as a result of surface tension in the alveoli is *inversely* affected by the radius of the alveolus, which means that the smaller the alveolus, the greater the alveolar pressure caused by the surface tension.
- When the alveoli have half the normal radius (50 instead of 100 micrometers), the pressures are doubled.
- This is especially significant in **small premature babies, many of whom have alveoli with radii less** than one quarter that of an adult person.

# PULMONARY SURFACTANT

- Surfactant does not normally begin to be secreted into the alveoli until between the sixth and seventh months of gestation, and in some cases, even later than that.
- So many premature babies have little or no surfactant in the alveoli when they are born, and their lungs have an extreme tendency to collapse, sometimes as great as six to eight times that in a normal adult person.
- This causes the condition **called *respiratory distress syndrome of the newborn*.** It is fatal if not treated with strong measures, especially properly applied continuous positive pressure breathing.

# DEAD SPACE AND ALVEOLAR VENTILATION

# Learning Objectives

- Define the following terms:
  - anatomic dead space, physiologic dead space, wasted (dead space) ventilation, total minute ventilation and alveolar minute ventilation.
- Compare anatomic and physiologic dead space.
- Describe the basic concept of measurement of dead space.
- Enlist the factors that changes the dead space.
- Define the following terms: hypoventilation, hyperventilation, Hypercapnia, Hypocapnia, hypopnea, and hyperpnea.

# Minute respiratory volume

- *Minute respiratory volume* is the total amount of new air moved into the respiratory passages each minute and is equal to the *tidal volume* times the *respiratory rate per minute*.
- The normal tidal volume is about 500 ml
- Normal respiratory rate is about 12 breaths/min
- $Ve = V_T \times RR$

  $= 500 \times 12$ b/min = 6000ml/min
- The minute respiratory volume is tidal volume times the respiratory rate/min
- Minute respiratory volume averages about 6 L/min.

- Pulmonary Ventilation = tidal volume × RR

  (ml/min) (ml/breath) (breaths/min)

# Dead space

Dead space is the portion of each tidal volume that does not take part in gas exchange.

There are two different ways to define dead space.

1. Anatomic &
2. Physiologic.

# Anatomic dead space

Anatomic dead space is the total volume of the conducting airways from the nose or mouth down to the level of the terminal bronchioles

Is about150 ml on the average in humans.

The anatomic dead space fills with inspired air at the end of each inspiration, but this air is exhaled unchanged.

Thus, assuming a normal tidal volume of 500 ml, about 30% of this air is "wasted" in the sense that it does not participate in gas exchange.

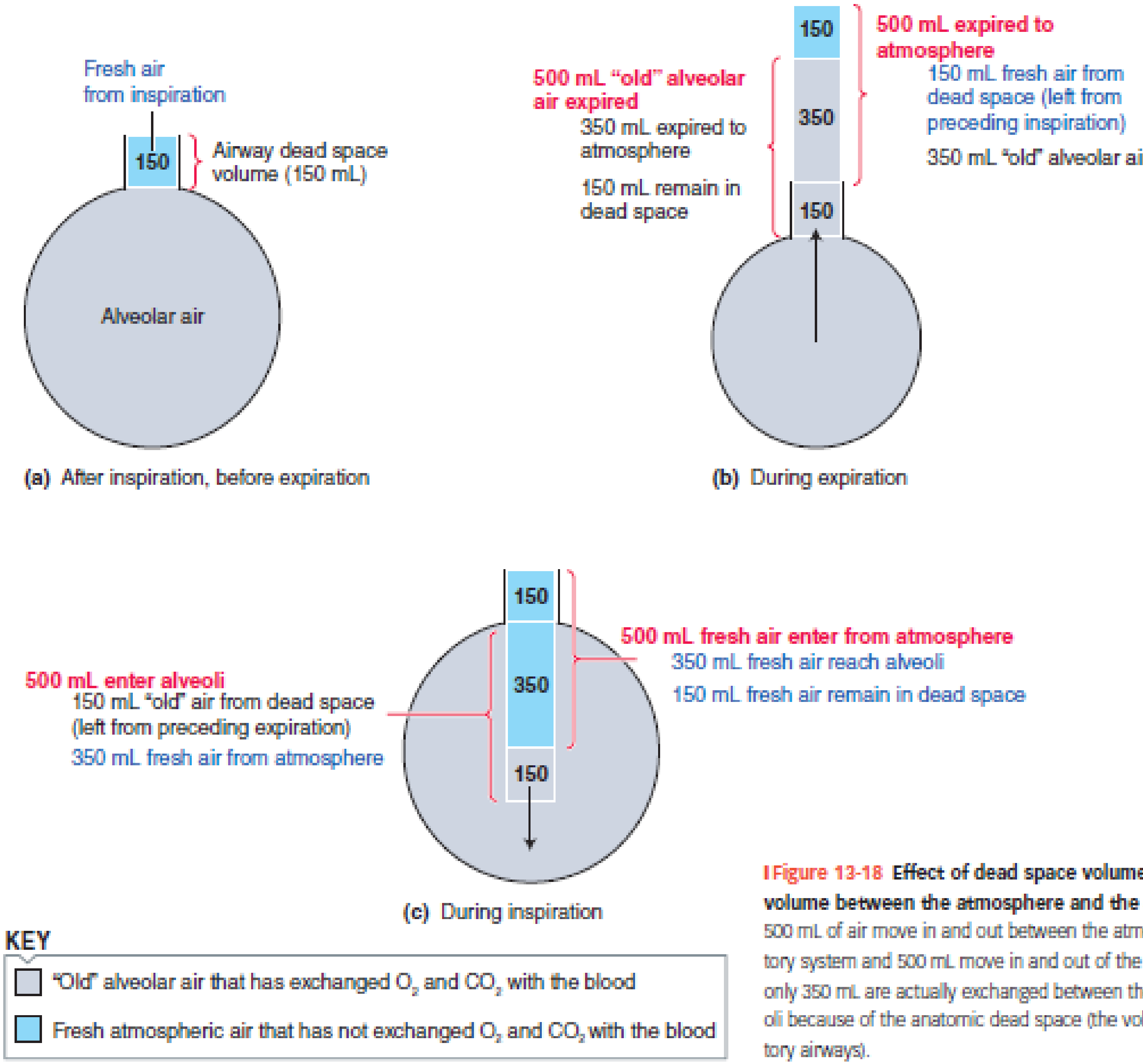



**Figure 13-18 Effect of dead space volume on exchange of tidal volume between the atmosphere and the alveoli.** Even though 500 mL of air move in and out between the atmosphere and the respiratory system and 500 mL move in and out of the alveoli with each breath, only 350 mL are actually exchanged between the atmosphere and the alveoli because of the anatomic dead space (the volume of air in the respiratory airways).

# Physiologic dead space

***Physiologic dead space*** includes all the non-respiratory parts of the bronchial tree included in anatomic dead space, but also factors in alveoli which are well-ventilated but poorly perfused and are therefore less efficient at exchanging gas with the blood.

***In healthy individuals***, the anatomic and physiologic dead spaces are roughly equivalent, since all areas of the lung are well perfused.

However, ***in disease states*** where portions of the lung are poorly perfused, the physiologic dead space may be considerably larger than the anatomic dead space. Hence, physiologic dead space is a more clinically useful concept than is anatomic dead space.

# Dead Space

**Anatomic dead space:**

- Respiratory system volume exclusive of alveoli
- Volume of conducting airways
- Approximately 150 ml
- With each expiration, first 150 ml expired is gas that occupies the dead space.
- Dead space is very disadvantageous for removing the expiratory gases from the lungs.

# Dead Space

**Total (physiological) dead space:**

- Volume of gas not equilibrating with blood; wasted ventilation
- Functional measurement
- In healthy individuals two dead spaces are identical.
- May be greater than the anatomic dead space in lung diseases in which there are V/Q defects.
- In disease states no exchange may take place between gas in some of alveoli and blood, and some of alveoli may be over ventilated
- Volume of gas in non-perfused alveoli  and any volume of air in alveoli in excess of that necessary to arterialize the blood in alveolar capillaries is part of dead space (nonequilibrating) gas volume

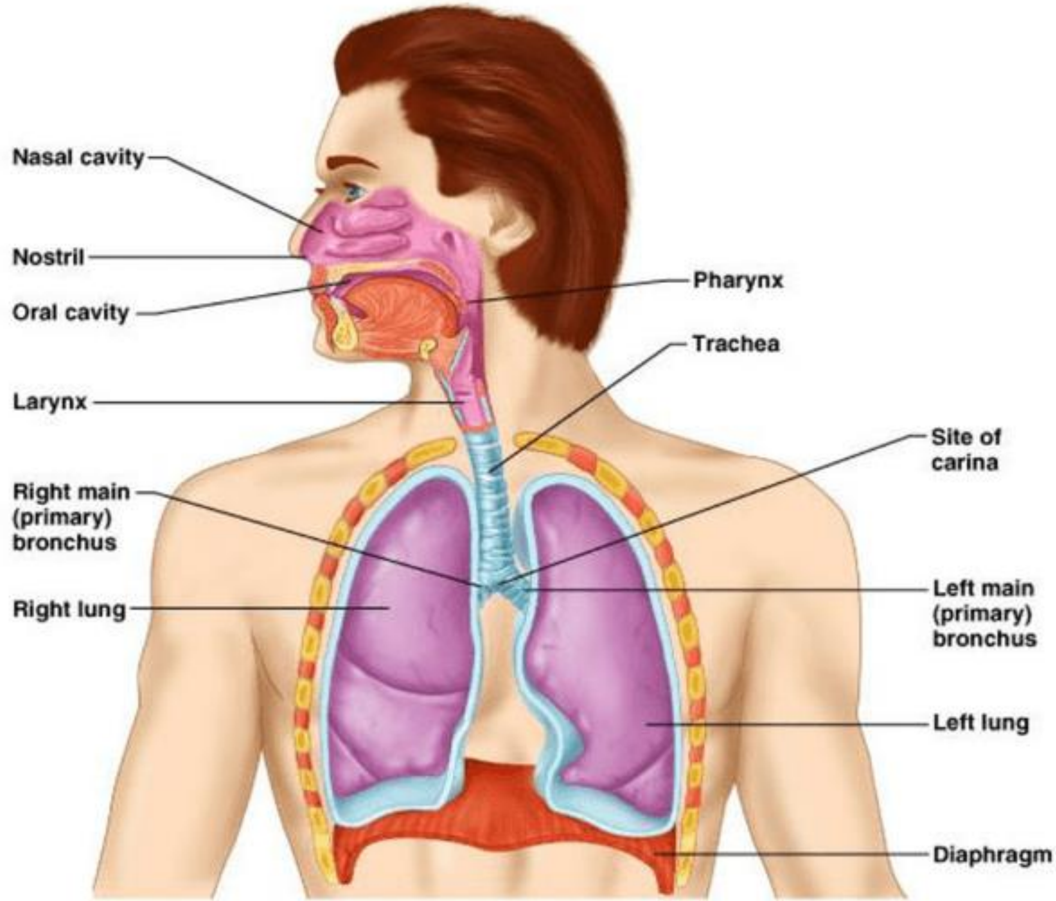
# The Respiratory Organs

Conducting zone

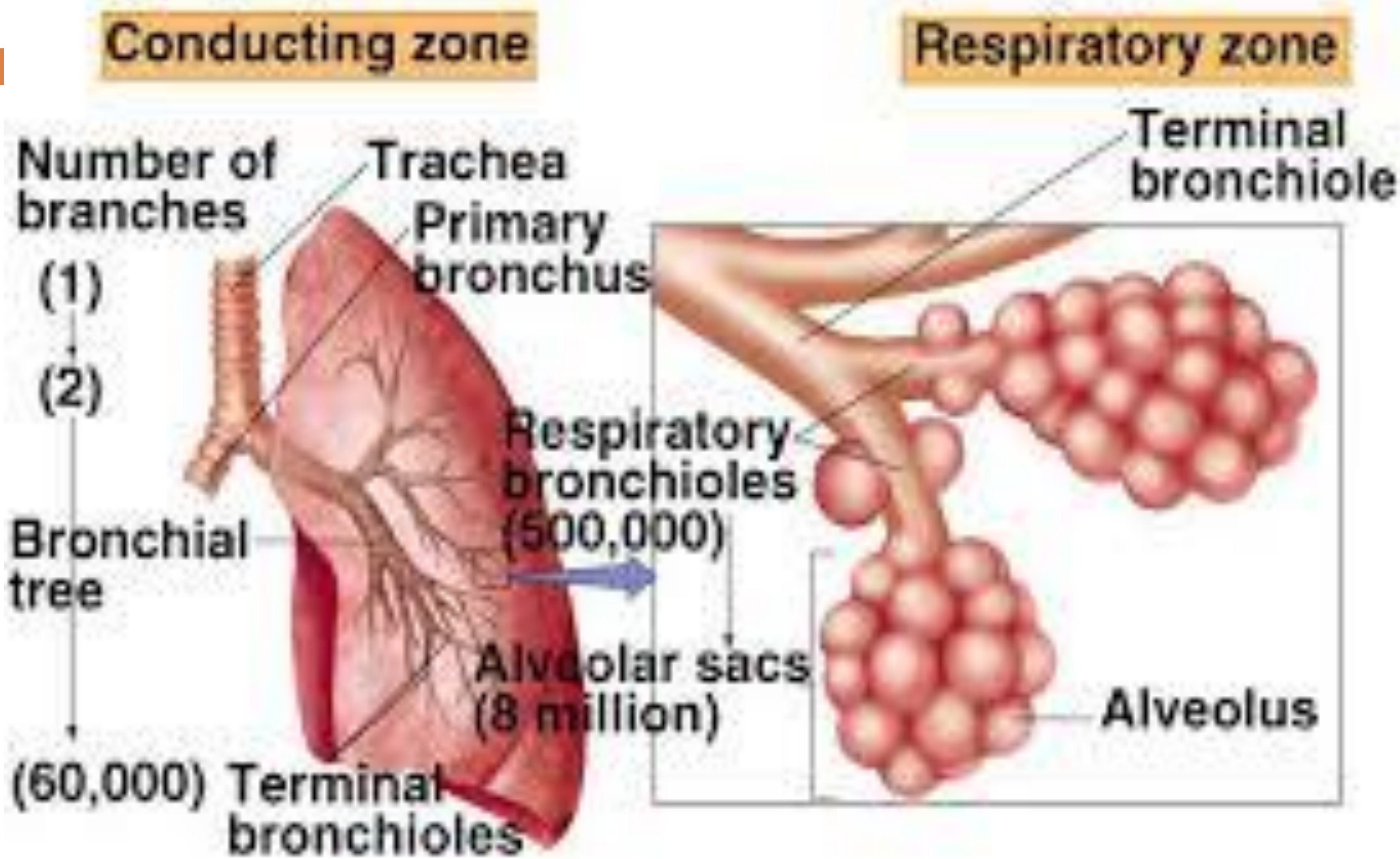
- Respiratory passages that carry air to the site of gas exchange
- Filters, humidifies and warms air

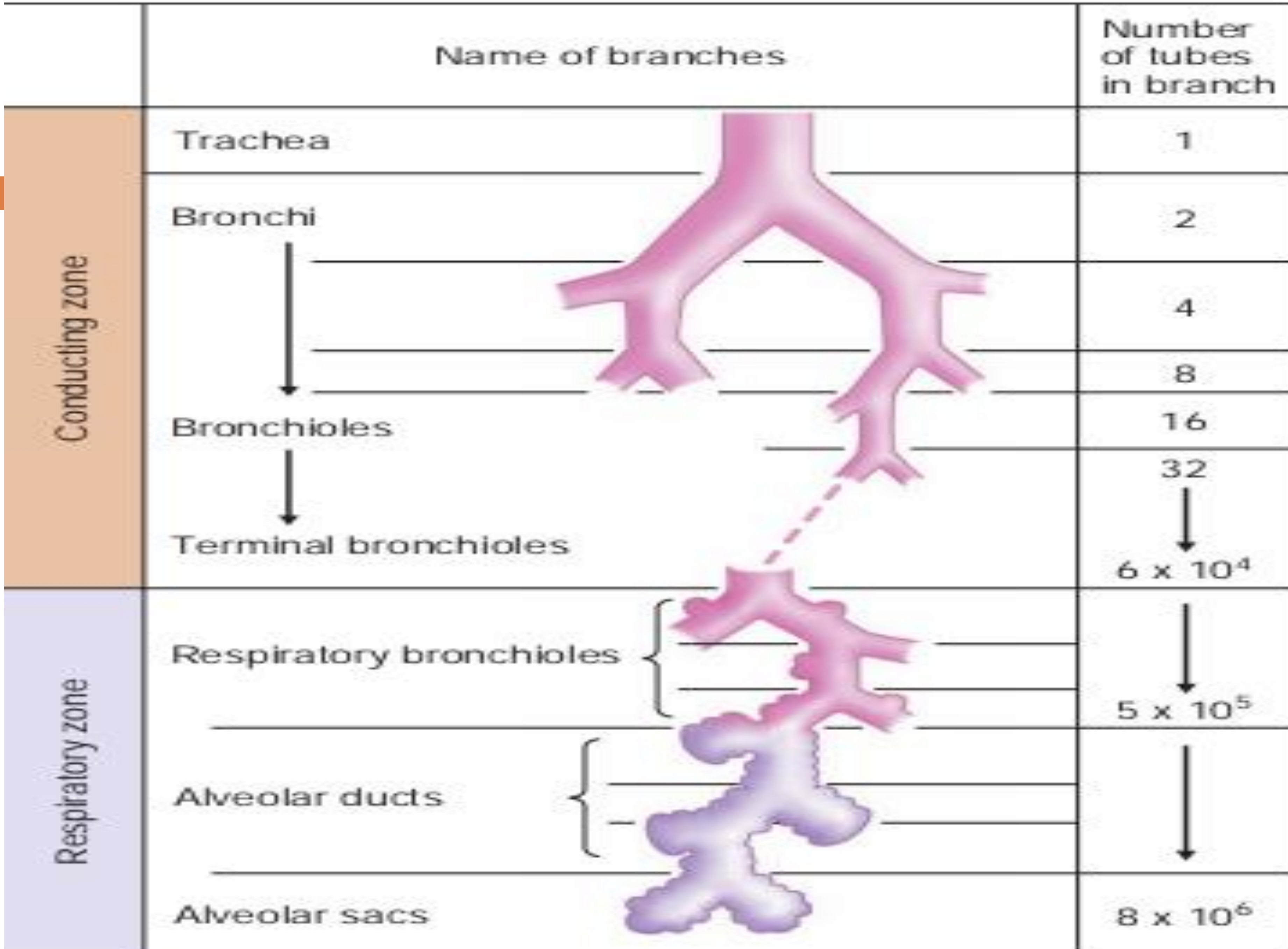
Respiratory zone

- Site of gas exchange
- Composed of
  - Respiratory bronchioles
  - Alveolar ducts
  - Alveolar sacs

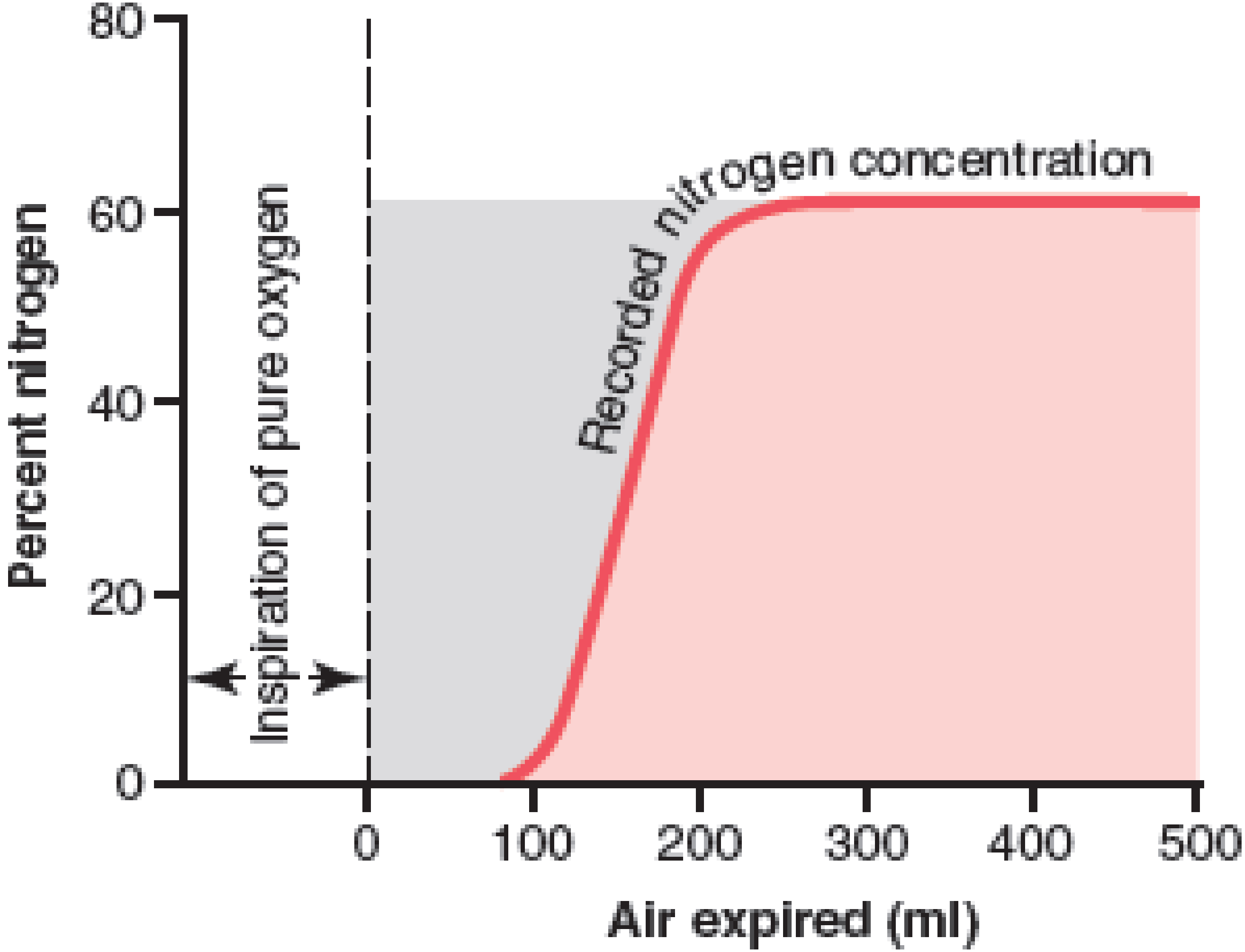


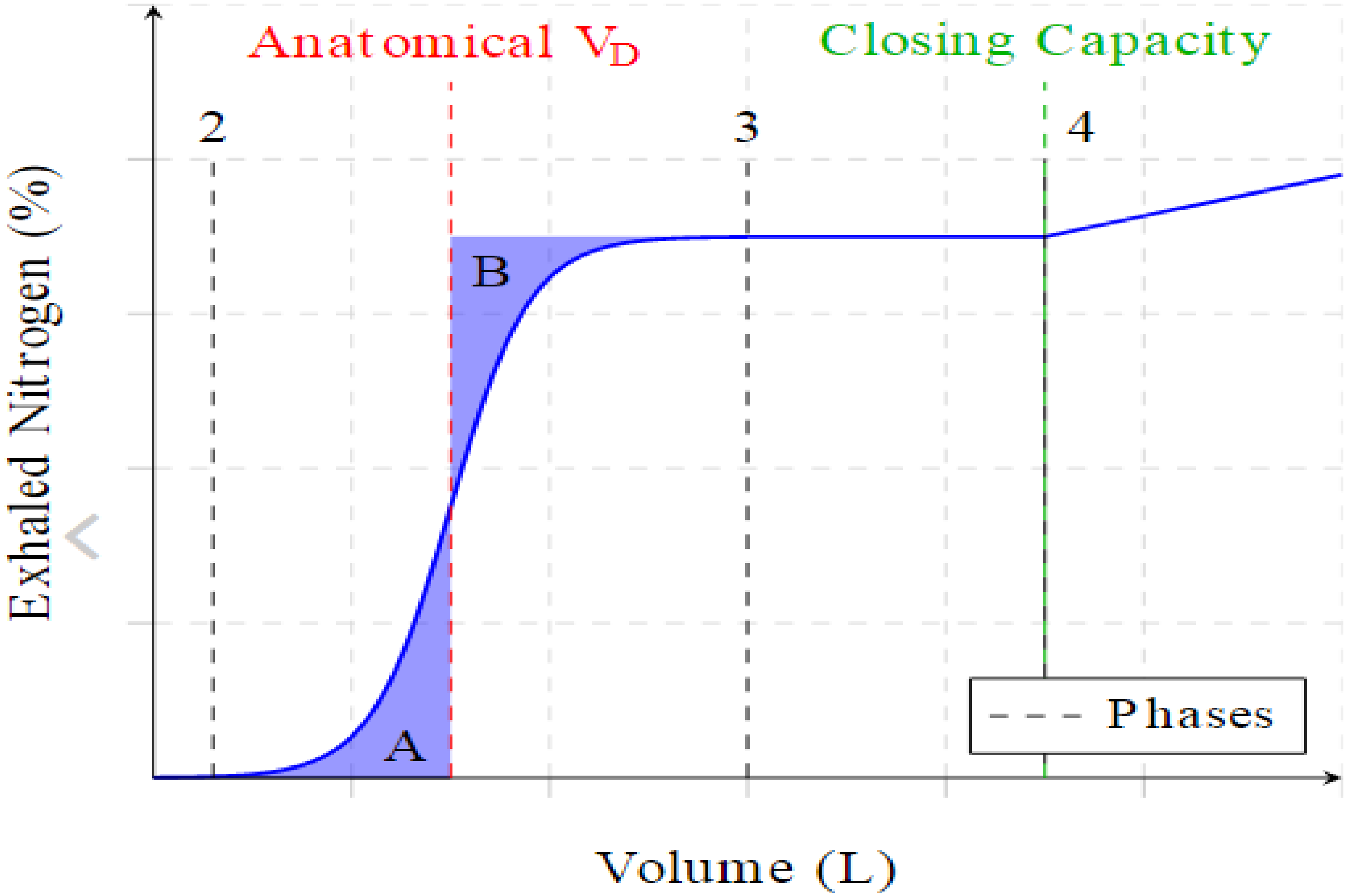

Conducting zone labeled


Conducting zone
Respiratory zone
Number of branches
(1)
(2)
(60,000)
Trachea
Primary bronchus
Bronchial tree
Terminal bronchioles
Terminal bronchiole
Respiratory bronchioles (500,000)
Alveolar sacs (8 million)
Alveolus


Name of branches
Number of tubes in branch
Conducting zone
Trachea
1
Bronchi
2
4
8
Bronchioles
16
32
Terminal bronchioles
6 x 10⁴
Respiratory zone
Respiratory bronchioles
5 x 10⁵
Alveolar ducts
Alveolar sacs
8 x 10⁶

# Fowlers Method for measuring Anatomical Dead space





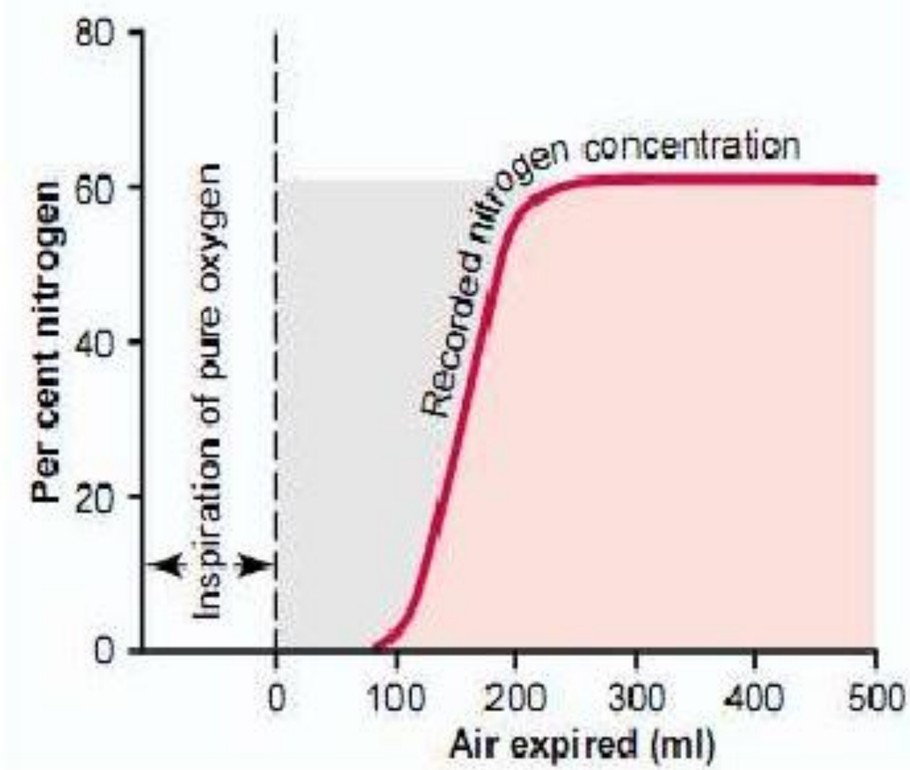
Anatomical $V_D$
Closing Capacity
2
3
4
B
A
Phases
Exhaled Nitrogen (%)
Volume (L)

# Anatomical DS: **Fowler's** Method

$$V_D = \frac{\text{Gray area} \times V_E}{\text{Pink area} + \text{Gray area}}$$

Assuming:
Gray area: 30 sq. cm
Pink area is 70 sq. cm
Total volume expired = 500 ml
**DS** would be:

$$\frac{30}{30+70} \times 500, \text{ or } 150 \text{ ml}$$



# Dead Space measurement

- Mid inspiration-Deep breath of Oxygen
- Exhales
- Nitrogen content of expired air is continuously measured
- Initial gas exhaled (phase I) is the gas that fills the dead space and consequently contains no N2.
- Phase II (mixture of dead space + alveolar gas)
- Phase III (alveolar gas)
- Volume of dead space is from peak inspiration to mid-portion of phase II.
- Phase III of single breath N2 curve terminate at CV
- CV is amount of air remaining in lungs when flow from lower section of lungs is severely reduced/halts together as small airways begins to close
- The gas in upper portion of lungs is rich in N2 than the gas in lower deeper portion because alveoli in upper

# Measurement

- **Physiological dead space is measured by Bohr's Method.**
- **Formula**: $V_D = \frac{V_T\,(PaCO2 - PeCO2)}{PaCO2}$
- $= \frac{500\,(42 - 28)}{42} = 150$ ml

$V_D$ = Dead space,
$V_T$ = Tidal volume,
Pa = partial pressure of alveoli,
Pe = partial pressure of expired air

# Anatomical dead space is affected by

**Size and Age**
Decreases when supine.

**Position of the neck and jaw**
Increased with neck extension.

**Lung volumes**
Increases by ~20ml per liter of additional lung volume.

**Airway caliber**
Bronchodilation increases airway diameter and therefore $V_D$.

# Causes of pathological dead space include

- Erect posture
- Decreased pulmonary artery pressure/impaired pulmonary blood flow
  - Hypovolemia
  - RV failure/Increased RV afterload:
    - Myocardial Infarction
  - Pulmonary Embolism
- Increased alveolar pressure
- COAD

# Dead Space measurement

***Alveolar ventilation*** is expressed as follows:

$$\text{Alveolar ventilation} = (\text{Tidal volume} - \text{Dead space}) \times \text{Breaths/min}$$

- **Sample problem:** A person with a tidal volume ($V_T$) of 0.5 L is breathing at a rate of 15 breaths/min. The $P_{CO_2}$ of his arterial blood is 40 mm Hg, and the $P_{CO_2}$ of his expired air is 36 mm Hg. What is his rate of alveolar ventilation?

$$\begin{aligned}
\text{Dead space} &= V_T \times \frac{P_{A_{CO_2}} - P_{E_{CO_2}}}{P_{A_{CO_2}}} \\
&= 0.5\,\text{L} \times \frac{40\,\text{mm Hg} - 36\,\text{mm Hg}}{40\,\text{mm Hg}} \\
&= 0.05\,\text{L} \\
\text{Alveolar ventilation} &= (\text{Tidal volume} - \text{Dead space}) \times \text{Breaths/min} \\
&= (0.5\,\text{L} - 0.05\,\text{L}) \times 15\,\text{Breaths/min} \\
&= 6.75\,\text{L/min}
\end{aligned}$$

# Rate of Alveolar Ventilation

$$\dot{V}_A = Freq \times (V_T - V_D)$$

- Freq is the frequency of respiration per minute
- $V_T$ is the tidal volume, and
- $V_D$ is the physiologic dead space volume.
- Normal tidal volume of 500 milliliters
- Normal dead space of 150 milliliters
- Respiratory rate of 12 breaths per minute
- Alveolar ventilation equals 12 × (500 - 150), or 4200 ml/min

# Effect of variations in respiratory rate and depth on alveolar ventilation

| Respiratory Rate | 30/min | 10/min |
|---|---|---|
| Tidal volume | 200ml | 600ml |
| Minute Volume | 6L | 6L |
| Alveolar ventilation | (200-150) *30 = 1500 ml | (600-150) *10 = 4500ml |

# Apnea/Dyspnea/Eupnea

- **Apnea:**

Transient cessation of breathing.

- **Dyspnea:**

Difficult or labored breathing.

- **Eupnea:**

Normal breathing

# Hypercapnia/Hypepnea

- **Hypercapnia:**

Excess $CO_2$ in the arterial blood

- **Hyperpnea:**

Increased pulmonary ventilation that matches increased metabolic demands, as in exercise

- **Hyperventilation:**

 Increased pulmonary ventilation in excess of metabolic requirements, resulting in decreased *P*$CO_2$ and respiratory alkalosis.

- **Hypoventilation:**

Underventilation in relation to metabolic requirements, resulting in increased *P*$CO_2$ and respiratory acidosis

- **Hypocapnia:**

 Below-normal $CO_2$ in the arterial blood.

# Hypoxia

## Insufficient $O_2$ at the cellular level

- **Anemic hypoxia:** Reduced O2-carrying capacity of the blood
- **Circulatory hypoxia:** Too little oxygenated blood delivered to the tissues; also known as stagnant hypoxia
- **Histotoxic hypoxia:** Inability of the cells to use available O2
- **Hypoxic hypoxia:** Low arterial blood *P*O2 accompanied by inadequate Hb saturation

# Anoxia

- Anoxia is a condition characterized by an absence of oxygen supply to an organ or a tissue.

# Hypoxia

- Cells of the body are not supplied by oxygen to their requirement or
- They are unable to utilize sufficient o2 to carry out their normal functions
- Anoxia
- Hypoxemia

Self-control is strength. Calmness is mastery. You have to get to a point where your mood doesn’t shift based on the insignificant actions of someone else. Don’t allow others to control the direction of your life. Don’t allow your emotions to overpower your intelligence.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A PLUS (+) CATEGORY (DENOTING SUPERB PERFORMANCE)
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