

# Breathing Mechanics & Basics of Gas Exchange

L.D. Lord

# Outline

- Ventilation vs Respiration
- “Dead space”, “Alveolar”, and “Minute”-ventilation
- Primary & Accessory muscles of respiration
- Respiratory system pressures (alveolar, intrapleural, transpulmonary)
- Clinical application: Pneumothorax
- Role of surfactant
- Spirometry
- Gas Exchange (basics)
- Practice Questions (WooClap!)

# Ventilation vs Respiration

- **“Breathing” = Ventilation + Respiration**
- **Ventilation** = the process by which we move air into and out of the lungs to enable gas exchange
- **Respiration** = gas exchange (CO<sub>2</sub> for O<sub>2</sub>), deep in lungs, between alveoli and pulmonary capillaries [**external respiration**] as well as gas exchange between tissues and the bloodstream [**internal respiration**]

# Ventilation vs Respiration: Anatomical Considerations

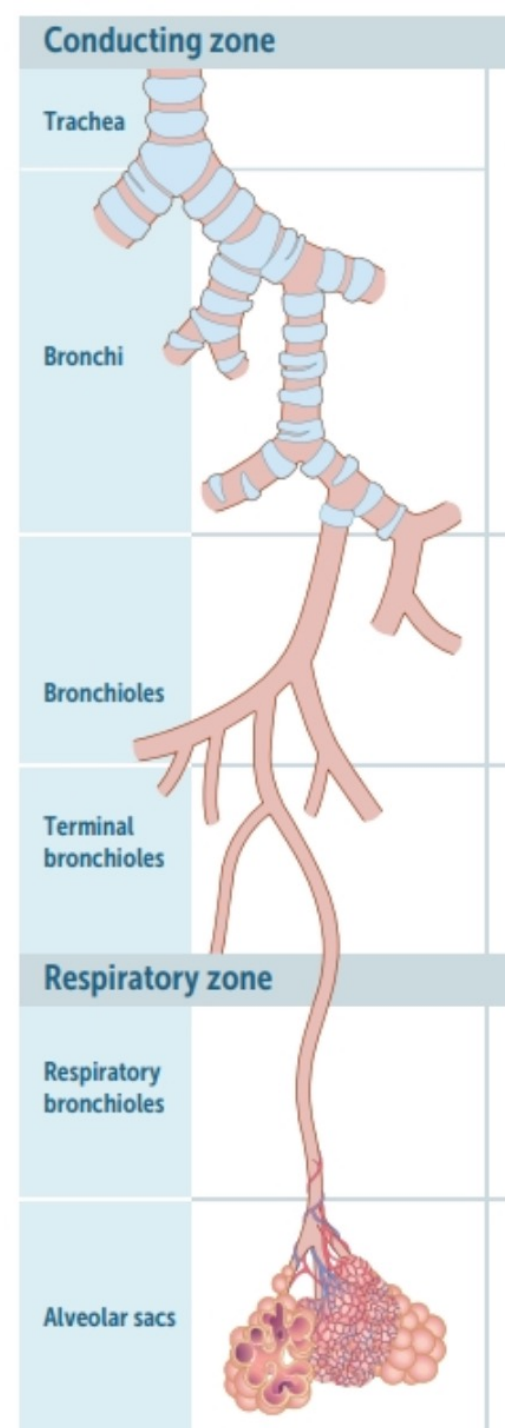
- **Conducting zone:**

trachea → 1° bronchus → 2° bronchi →  
3° bronchi → bronchioles → terminal  
bronchioles → ...

- ★ • **Respiratory zone\* (gas exchange):**

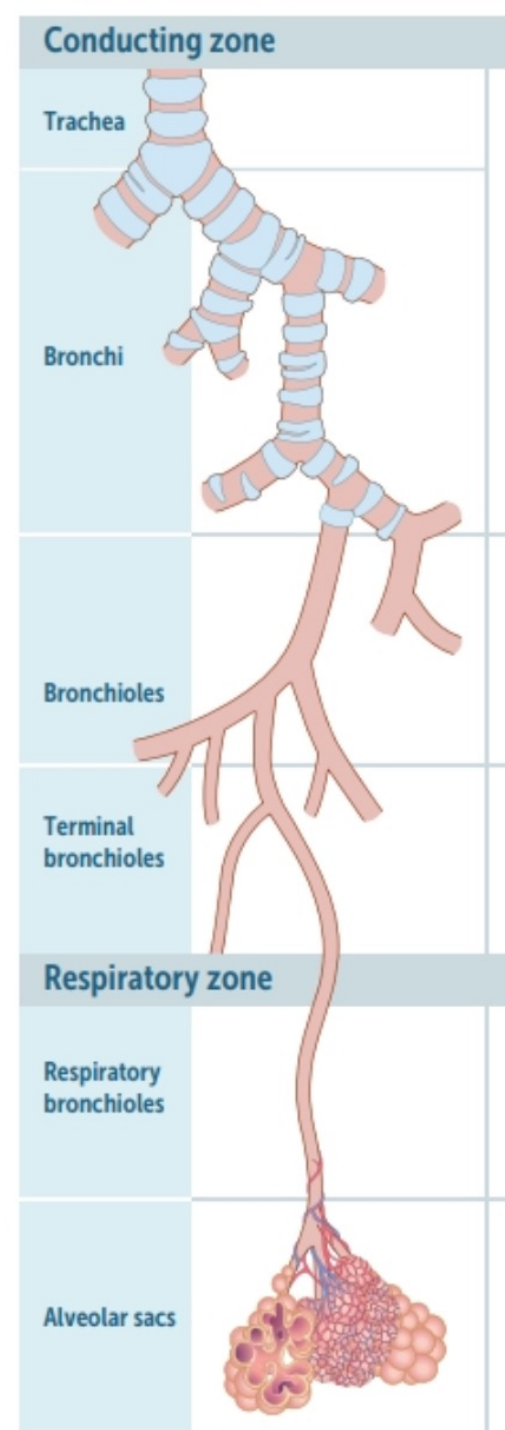
respiratory bronchioles → **alveoli**

- ★ *Gas exchange is exclusive to the respiratory zone*



# Dead space ventilation

- **NOT** all the air we breathe participates in gas exchange
- **Anatomic dead space:**  
Areas of the lung that are **structurally incapable of gas exchange**: trachea, bronchi, and terminal bronchioles
- **Alveolar dead space :**  
**Alveoli** that do not participate in gas exchange due to **insufficient perfusion** (usually pathological)
- **Physiologic (total) dead space :**  
Anatomic dead space + Alveolar dead space



# Minute ventilation (VE)

- **Minute ventilation (VE)** = rate of air entering the lungs per minute (ml / min)

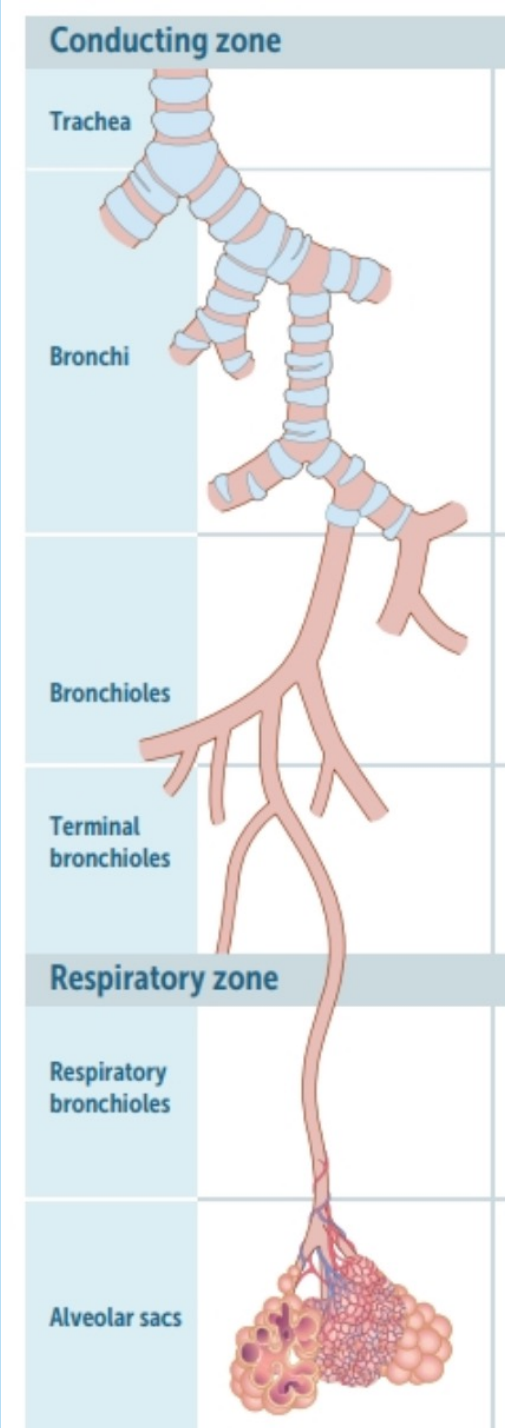
[does not matter whether or not air reaches alveoli and participates in gas exchange]

$$VE = V_t * RR$$

$V_t$  = tidal volume\* (ml) (~500ml)

RR = respiratory rate

*\*Tidal volume is the amount of air that moves in or out of the lungs with each respiratory cycle*



# Alveolar ventilation

- **Alveolar ventilation ( $V_a$ )** = rate of air (ml / min) that reaches the alveoli and participates in gas exchange

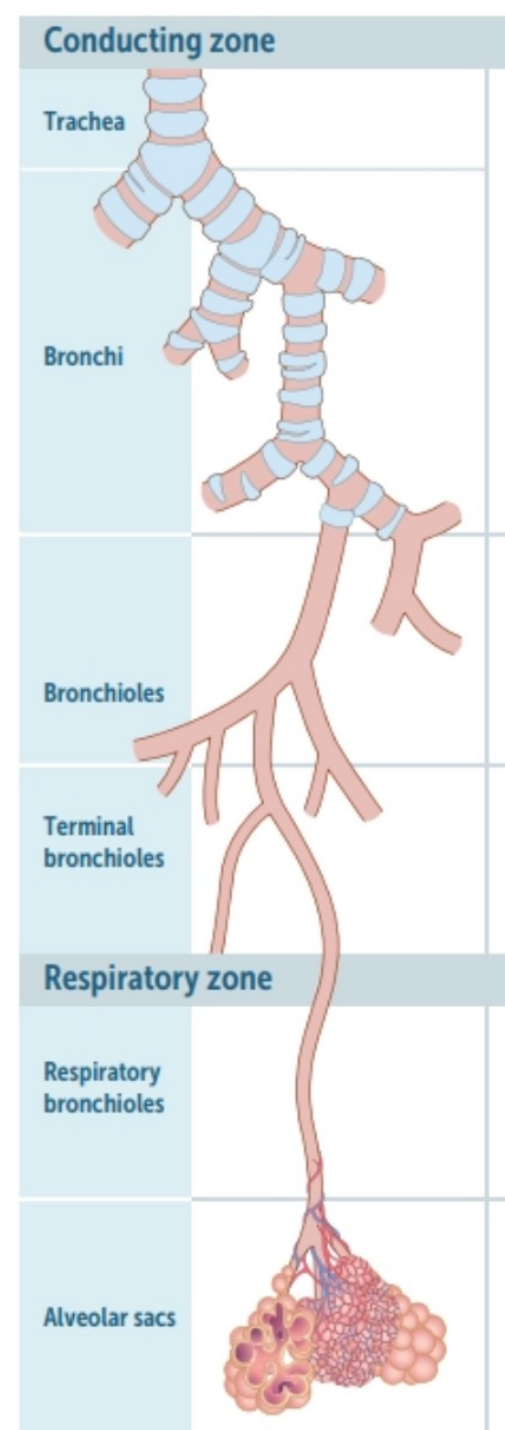
$$V_a = (V_t - V_d) * RR$$

$V_t$  = tidal volume (ml) [ $\sim 500$ ml]

$V_d$  = physiologic (total) dead space (ml)

RR = respiratory rate

*\*Tidal volume is the amount of air that moves in or out of the lungs with each respiratory cycle*



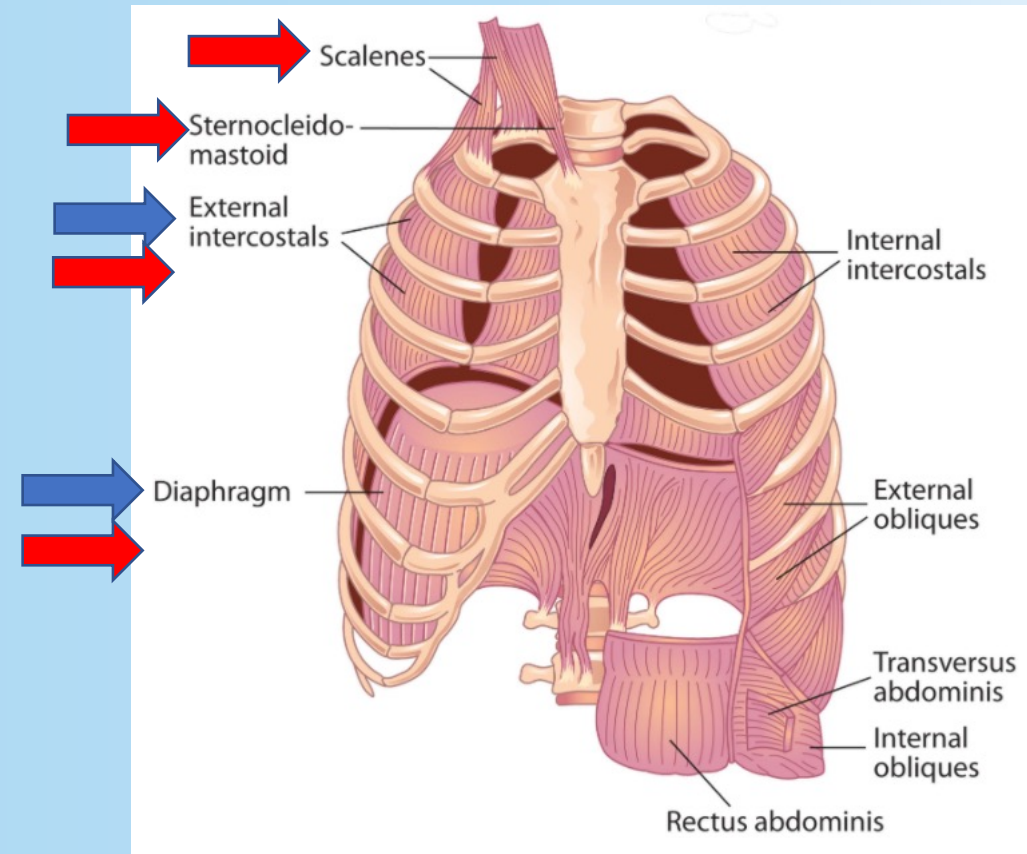
# Outline

- ~~Ventilation vs Respiration~~
- ~~“Dead space”, “Alveolar”, and “Minute”-ventilation~~
- Primary & Accessory muscles of respiration
- Respiratory system pressures (alveolar, intrapleural, transpulmonary)
- Clinical application: Pneumothorax
- Role of surfactant
- Spirometry
- Gas Exchange (basics)
- Practice Questions (WooClap!)



# Muscles of Respiration: Inspiration

- Normal / quiet inspiration is driven by the diaphragm\* with some assistance from the **external intercostal muscles**
- Deep / forced inspiration requires the diaphragm + external intercostals, but **in addition to these: SCM, scalenes, serratus anterior**



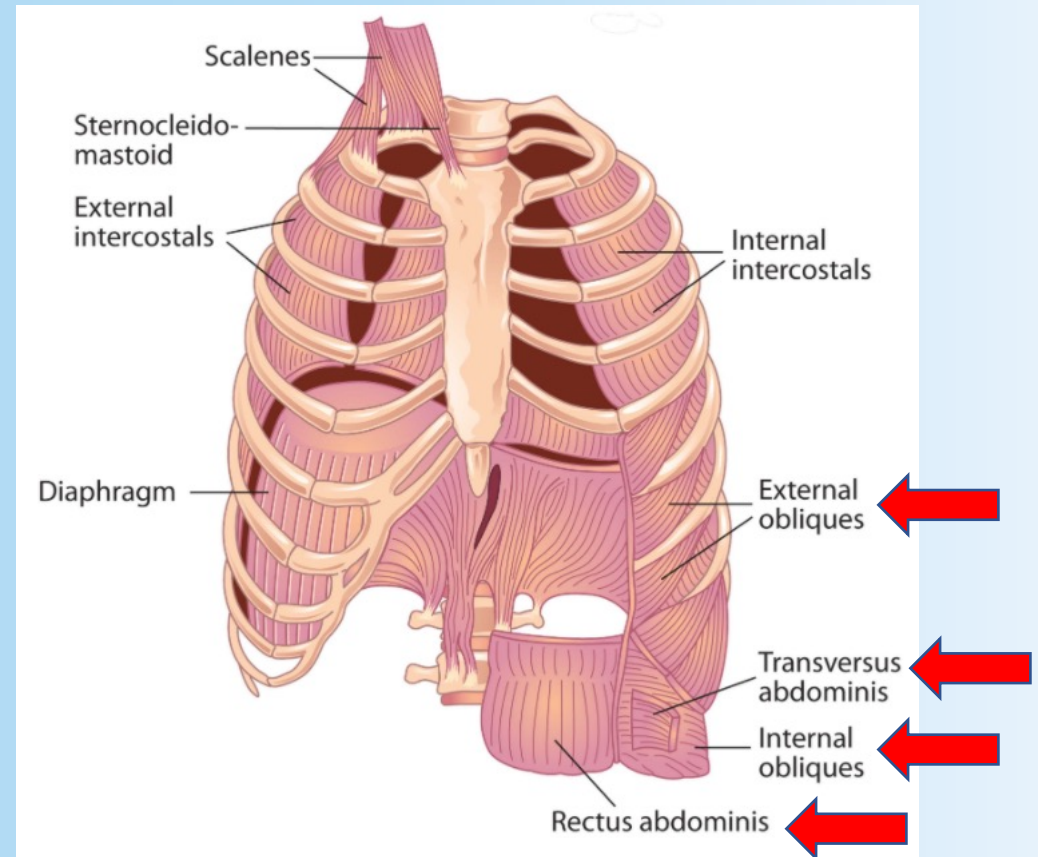
*diaphragm contracts during inspiration\**

# Muscles of Respiration: Expiration

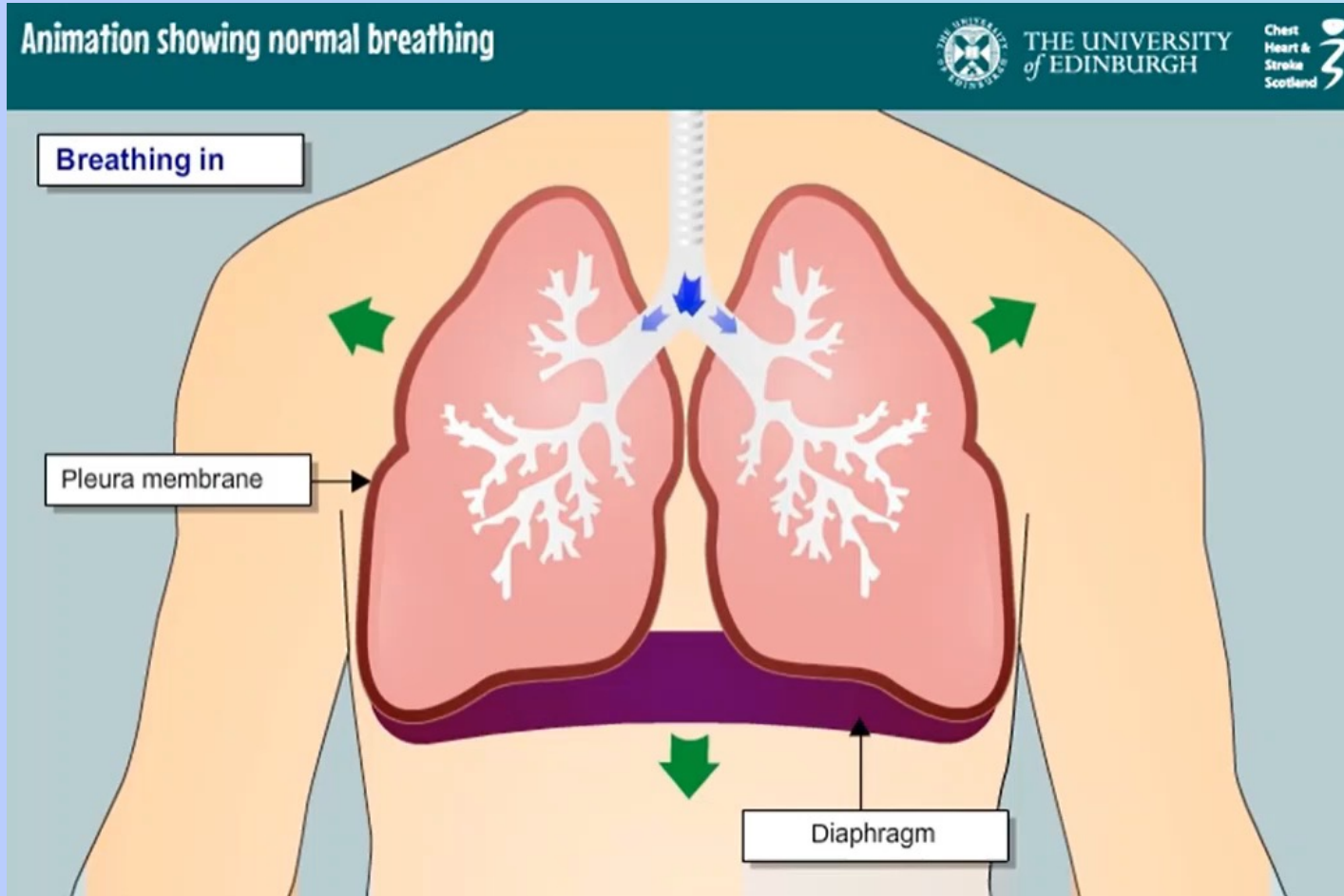
- Normal / quiet expiration is a **passive activity** that occurs once the diaphragm relaxes

- Deep / forced expiration

principally involves **abdominal muscles: rectus+transeversus abdominis, internal+external obliques**



Q: What's the goal of all this muscle activity?  
A: To create pressure gradients (so you can breathe)



Boyles Law:  $P_1V_1 = P_2V_2$

$$P \propto \frac{1}{V}$$

**Inspiration**

**Diaphragm contracts (flattens)**

**lung/alveolar vol  $\uparrow$**

**alveolar pressure  $\downarrow$**

$$P_{\text{atm}} > P_{\text{alveolar}}$$

**Air flows into the lungs**

★ As with any fluid, air wants to flow **DOWN** its pressure gradient

# Boyle's Law. Inspiration & Expiration

$$\text{Boyles Law: } P_1V_1 = P_2V_2$$

$$P \propto \frac{1}{V}$$

## Inspiration

**Diaphragm contracts (flattens)**

**lung/alveolar vol ↑**

**alveolar pressure ↓**

$$P_{\text{atm}} > P_{\text{alveolar}}$$

**Air flows INTO the lungs**

## Expiration

**Diaphragm relaxes**

**lung/alveolar vol ↓**

**alveolar pressure ↑**

$$P_{\text{atm}} < P_{\text{alveolar}}$$

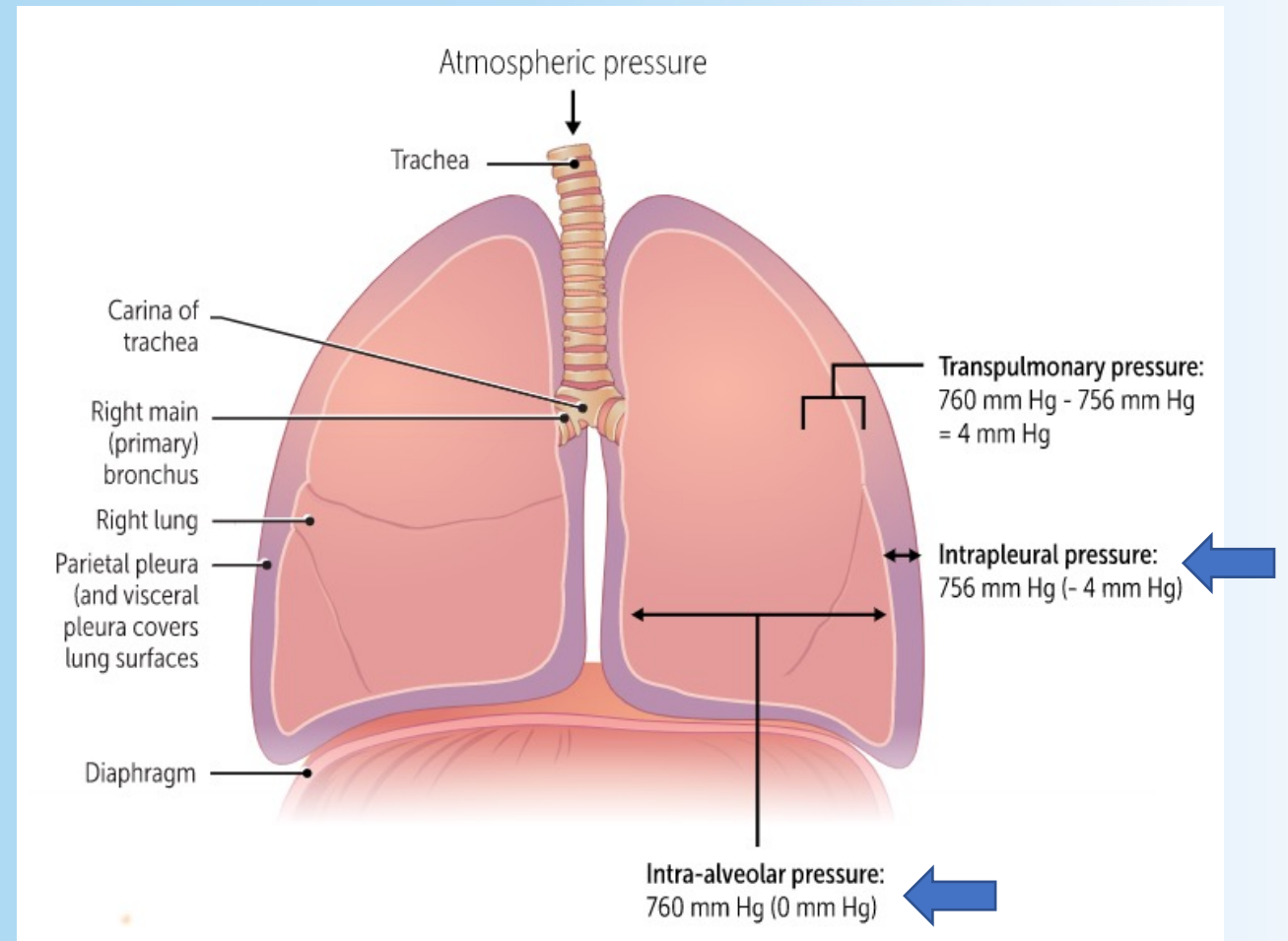
**Air flows OUT OF the lungs**

# Outline

- ~~Ventilation vs Respiration~~
- ~~“Dead space”, “Alveolar”, and “Minute”-ventilation~~
- ~~Primary & Accessory muscles of respiration~~
- ★ • Respiratory system pressures (alveolar, intrapleural, transpulmonary)
- Clinical application: Pneumothorax
- Role of surfactant
- Spirometry
- Gas Exchange (basics)
- Practice Questions (WooClap!)

# Respiratory system pressures: Overview

- **Intra-alveolar pressure** (aka intrapulmonary pressure)
- **Intrapleural pressure**

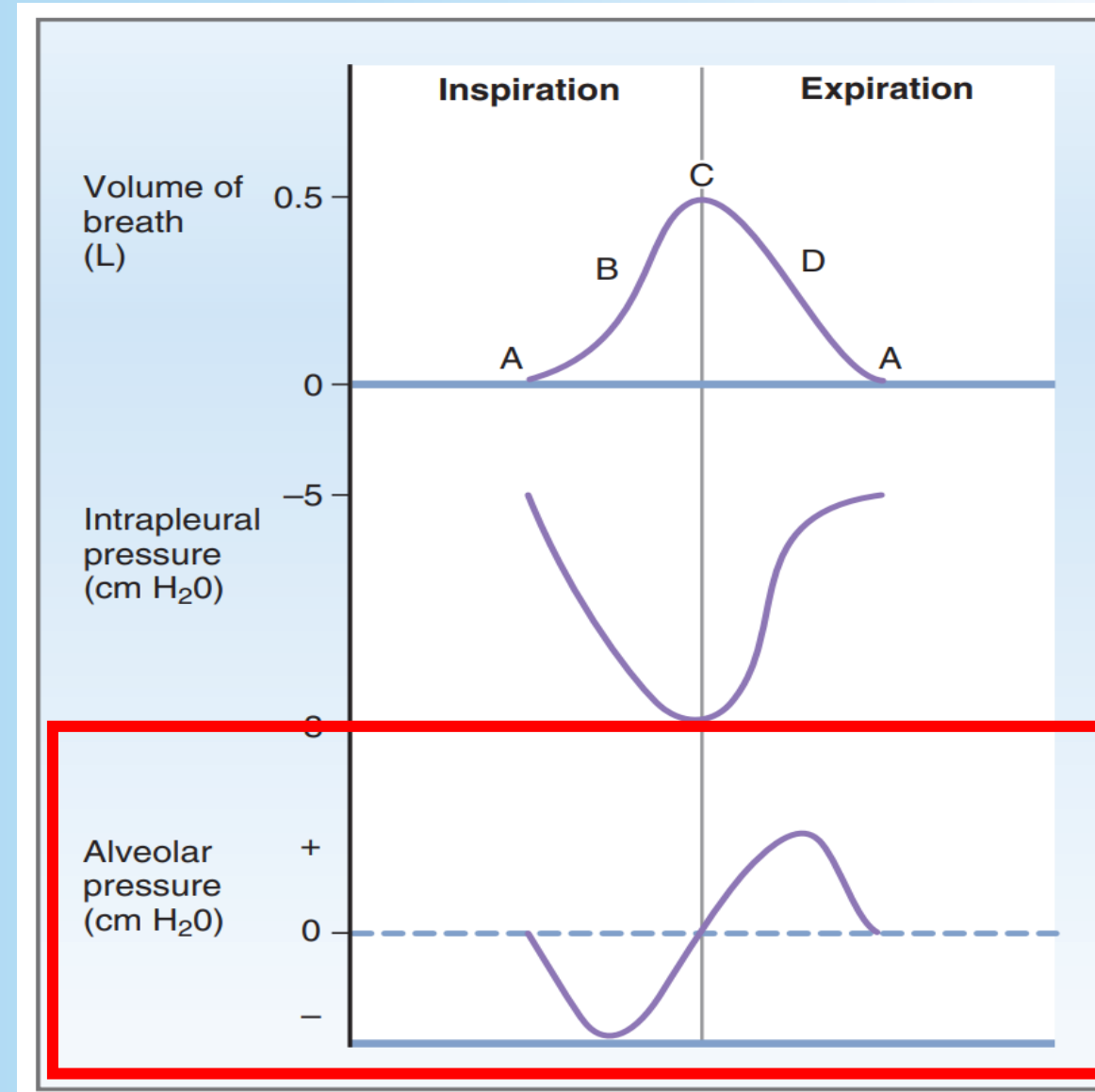




# Respiratory system pressures: Alveolar Pressure (aka intrapulmonary pressure)

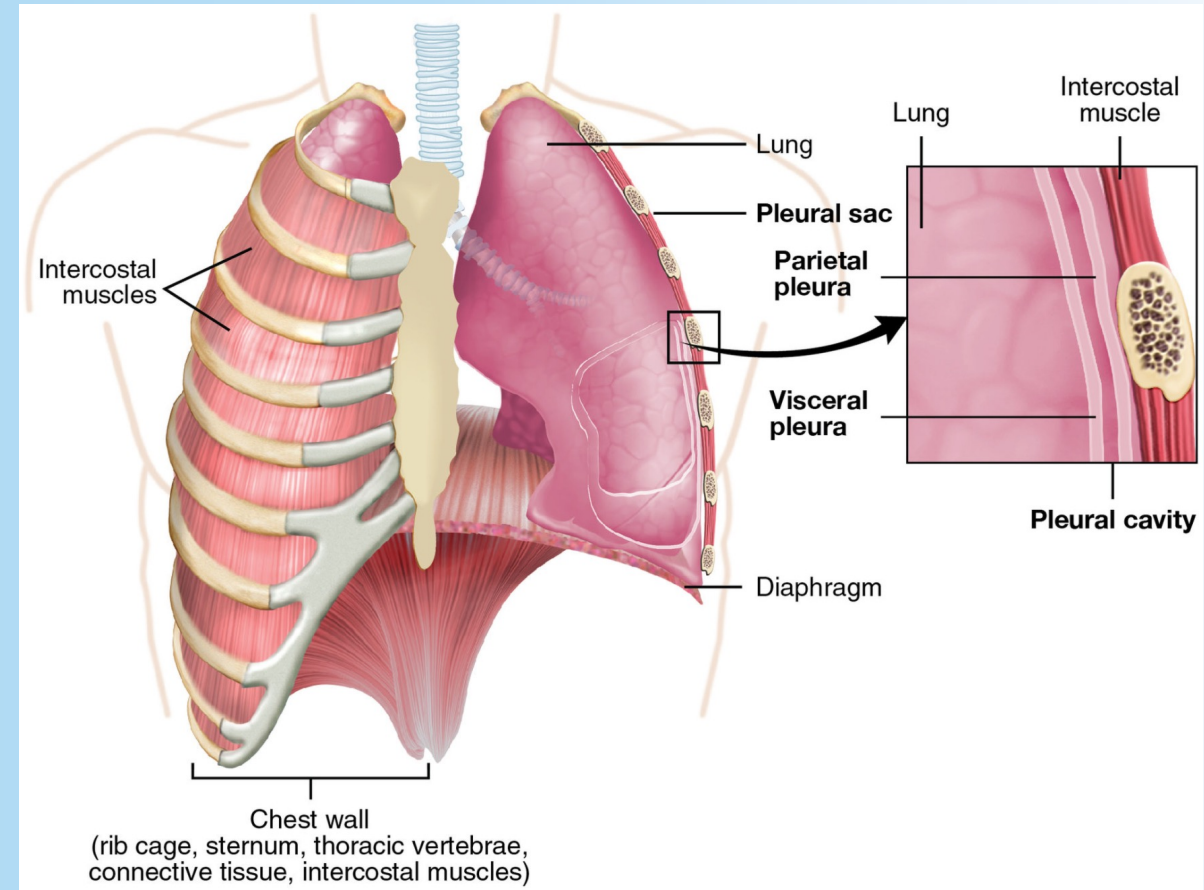
- **Alveolar pressure** is the pressure within the alveoli.
- **Alveolar pressure** changes during the respiratory cycle.
- Inspiration:  $P_{\text{alveolar}} < P_{\text{atm}}$
- Expiration:  $P_{\text{alveolar}} > P_{\text{atm}}$
- No air movement:  $P_{\text{alveolar}} = P_{\text{atm}}$

★ "negative pressure" = negative with respect to  $P_{\text{atm}}$   
i.e. below 760 mmHg. **NOT**  $< 0$  mmHg



# Respiratory system pressures: Intrapleural pressure (i)

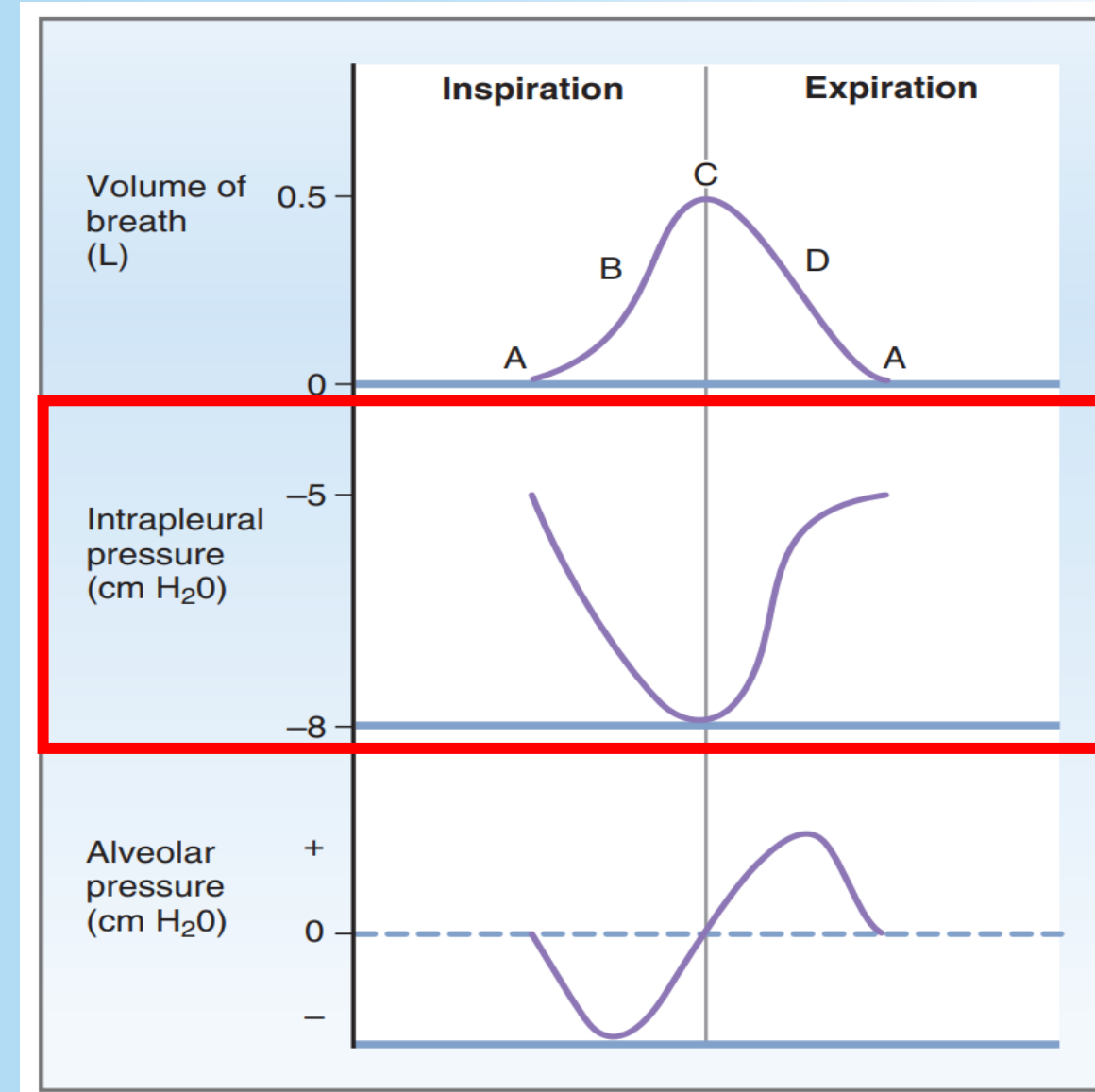
- **Intrapleural pressure** is the pressure within the pleural space (between visceral & parietal pleura)
- **Always negative pressure** under physiological conditions
- **Negative pressure prevents the lungs from collapsing** AND prevents the chest wall from springing out





# Respiratory system pressures: Intrapleural pressure (ii)

- **Always negative** under physiological conditions
- **during inspiration**, the pleural space volume expands (as diaphragm pulls downwards) and **intrapleural pressure becomes “even more negative”**
- **during expiration**, **intrapleural pressure becomes “less negative”, but still negative!**

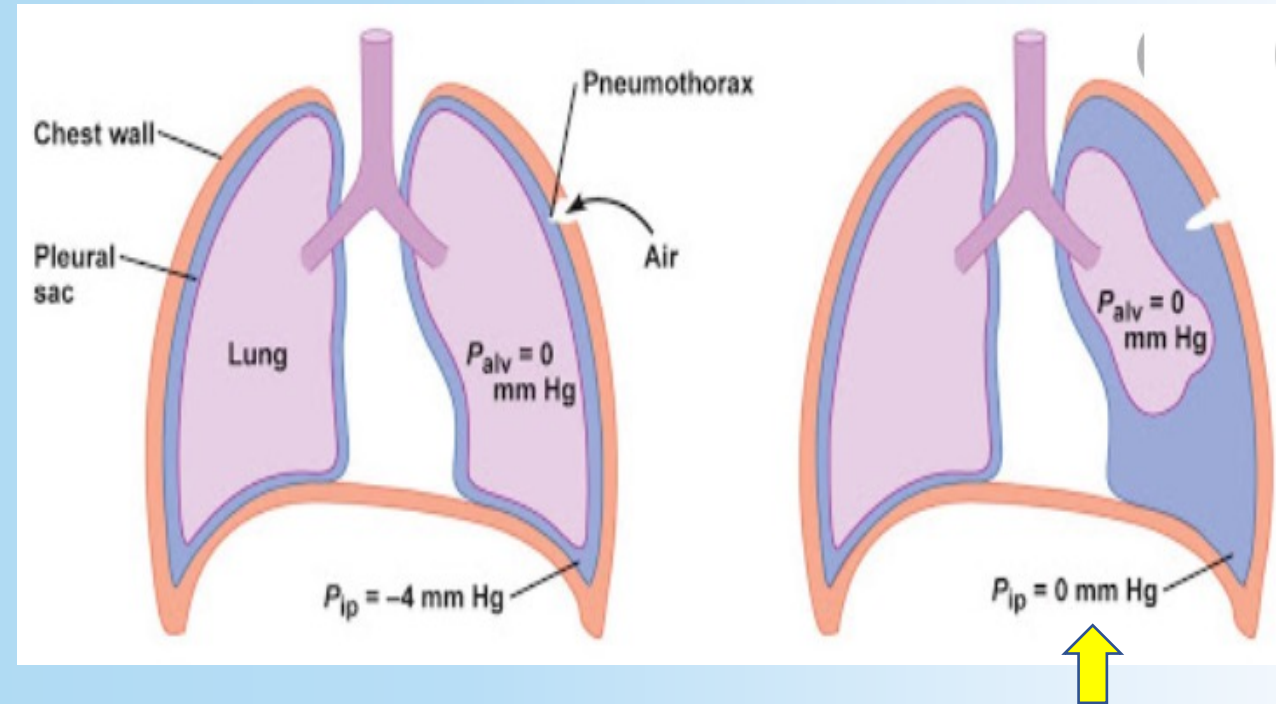


# Outline

- ~~Ventilation vs Respiration~~
- ~~“Dead space”, “Alveolar”, and “Minute”-ventilation~~
- ~~Primary & Accessory muscles of respiration~~
- ★ • ~~Respiratory system pressures (alveolar, intrapleural, transpulmonary)~~
  - Clinical application: Pneumothorax
  - Role of surfactant
  - Spirometry
  - Gas Exchange (basics)
  - Practice Questions (WooClap!)

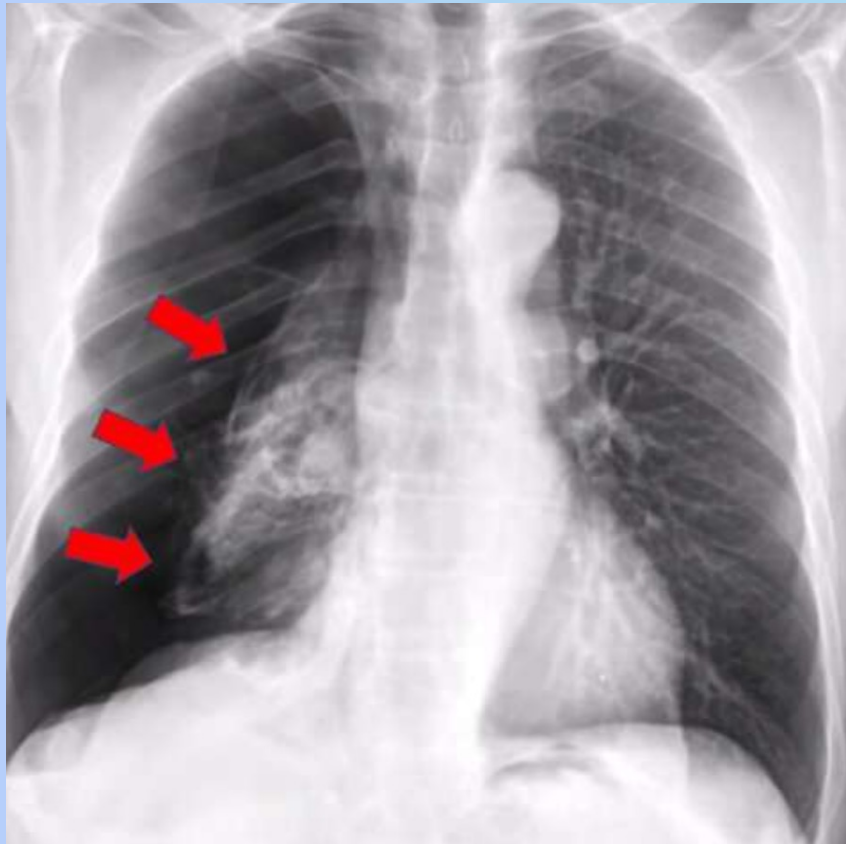
# Pneumothorax (i)

- Usually due to penetrating injury (i.e. stab & gun shot wounds) to chest wall
- **Negative intrapleural pressure is lost as air inappropriately enters the intrapleural space**
- Alveoli's **natural tendency to recoil** (due to elasticity) is now **unopposed**
- **Affected lung collapses & chest wall expands**

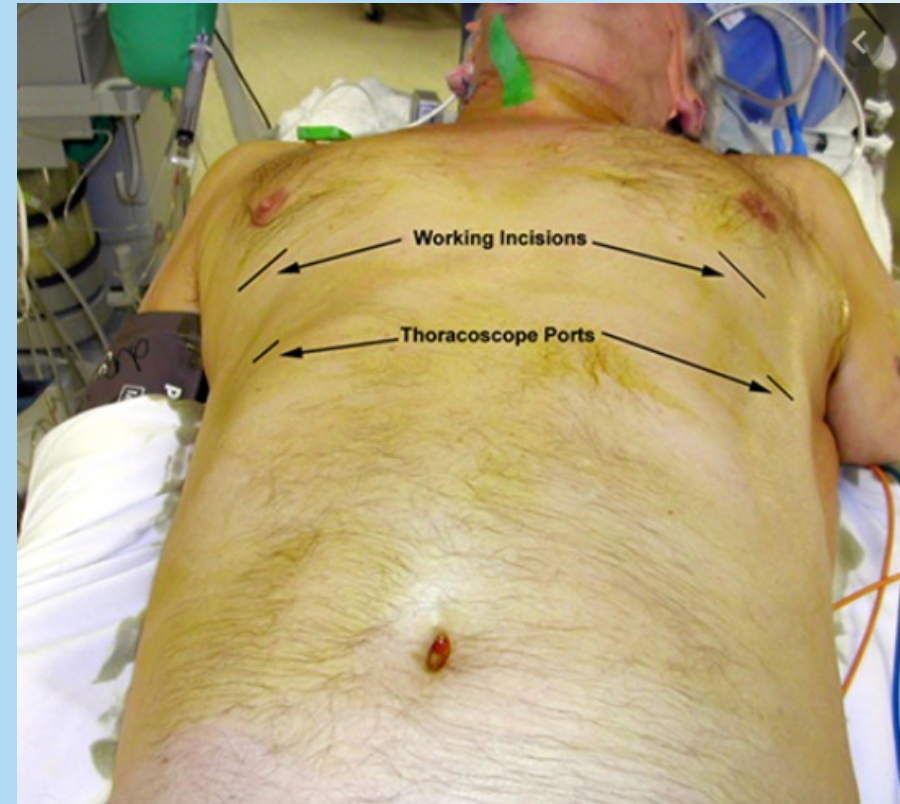


# Pneumothorax (ii)

**Collapsed lung**



**Chest wall expansion**

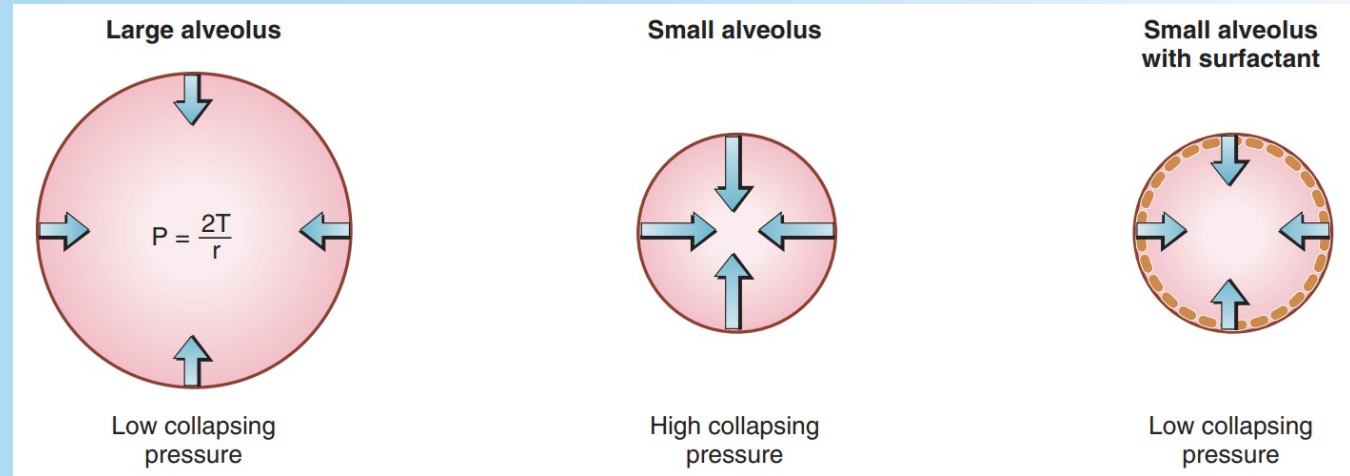


# Outline

- ~~Ventilation vs Respiration~~
- ~~“Dead space”, “Alveolar”, and “Minute”-ventilation~~
- ~~Primary & Accessory muscles of respiration~~
- ★ • ~~Respiratory system pressures (alveolar, intrapleural, transpulmonary)~~
- ~~Clinical application: Pneumothorax~~
- Role of surfactant
- Spirometry
- Gas Exchange (basics)
- Practice Questions (WooClap!)

# Role of surfactant (i)

- Surfactant is essential to survival.
- Without surfactant, your **alveoli would collapse**
- **Surfactant ↓ alveolar surface tension**
- Smaller alveoli are at greater risk of collapse than large alveoli



- Law of Laplace:

$$P_{collapsing} = \frac{2 * T}{r}$$

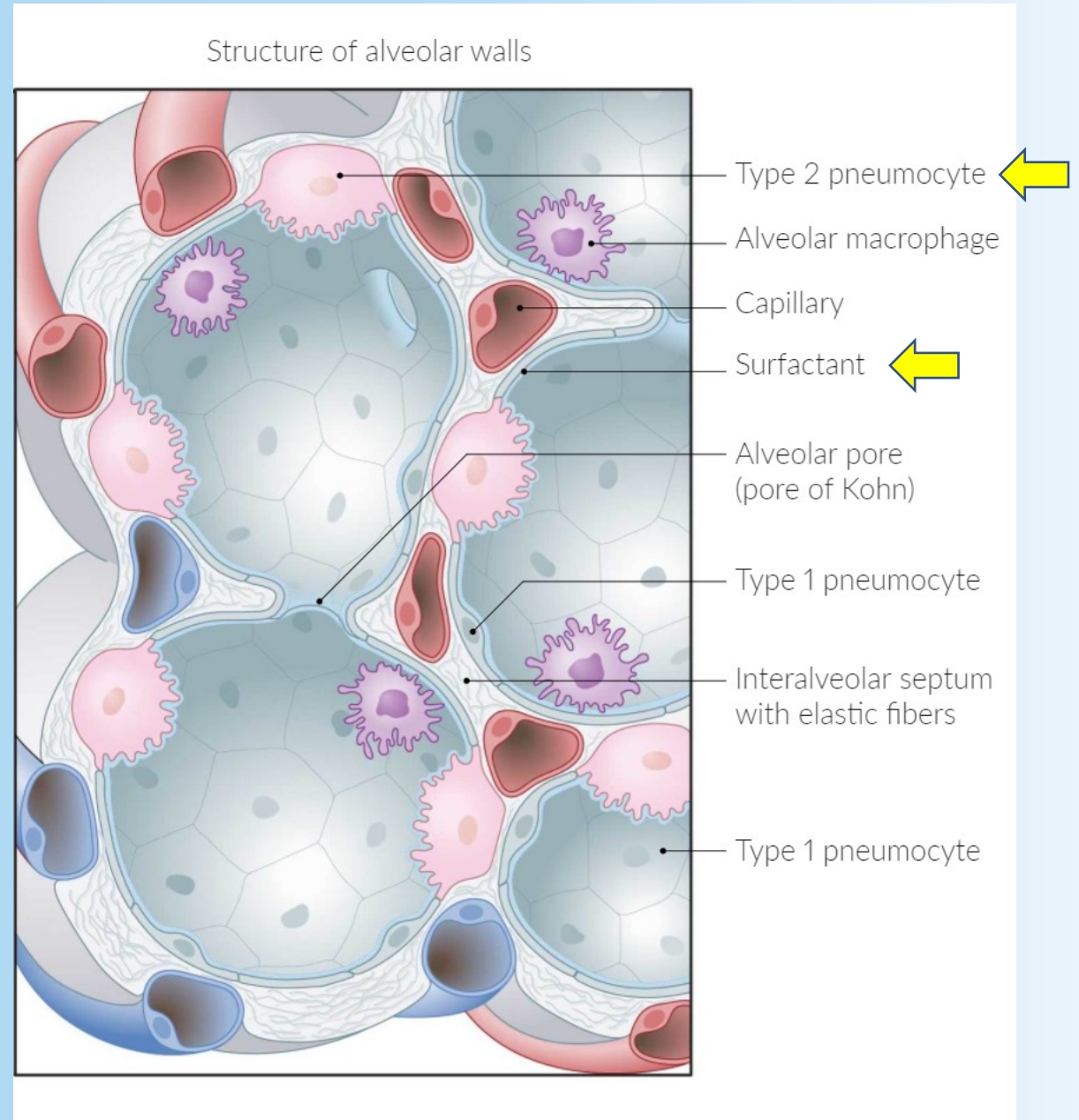
T = surface tension

r = alveolar radius



# Role of surfactant (ii)

- Surfactant is made by **Type 2 pneumocytes**
- Surfactant is composed of **90% lipids**, and reduces surface tension at the air/liquid interface



# Role of surfactant (iii): Neonatal respiratory distress syndrome

- Premature birth earlier than week 24 → **NO surfactant** present
- Premature birth between week 24 – week 35 → “**uncertain surfactant status**”
- **Lack of surfactant → alveolar collapse → collapsed alveoli cannot be ventilated**



**Treatment:** Endotracheal admin of artificial surfactant + nasal CPAP



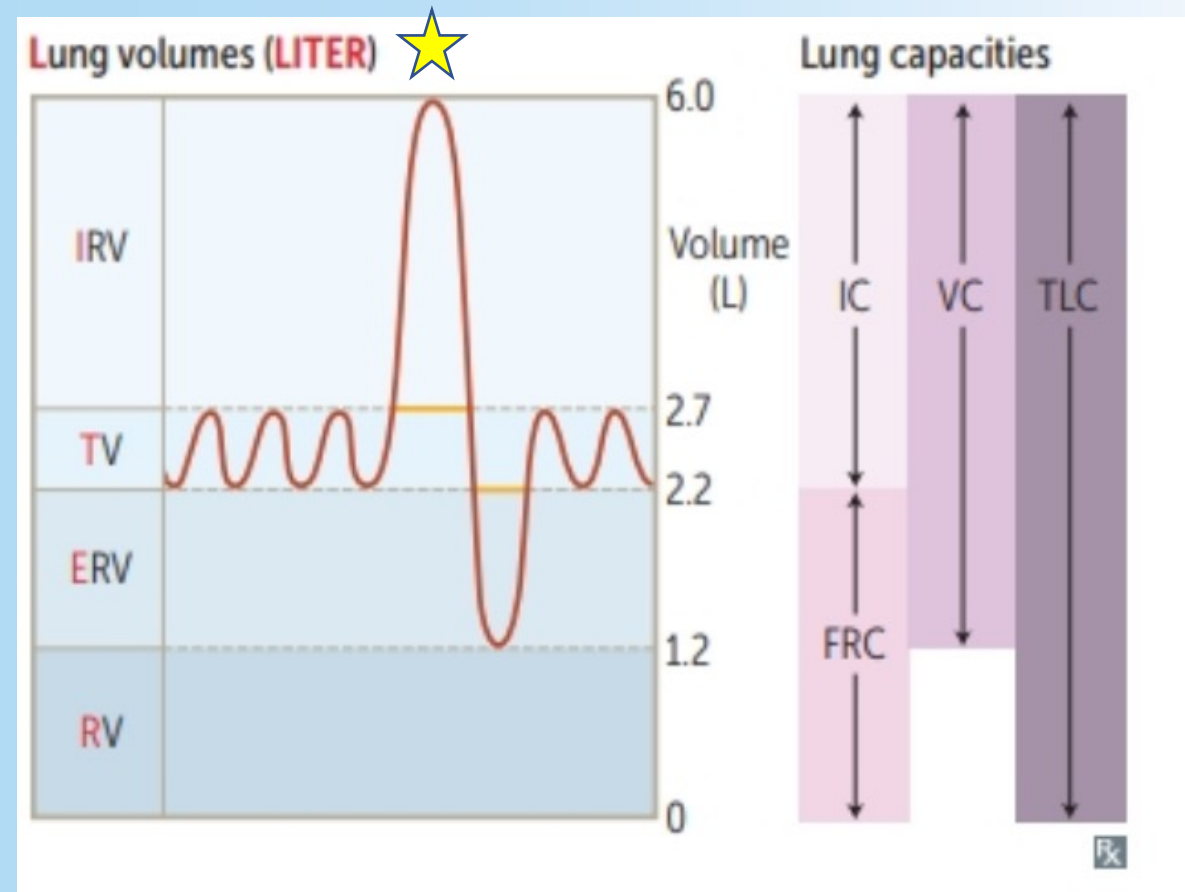
# Outline

- ~~Ventilation vs Respiration~~
- ~~“Dead space”, “Alveolar”, and “Minute”-ventilation~~
- ~~Primary & Accessory muscles of respiration~~
- ★ • ~~Respiratory system pressures (alveolar, intrapleural, transpulmonary)~~
- ~~Clinical application: Pneumothorax~~
- ~~Role of surfactant~~
- Spirometry
- Gas Exchange (basics)
- Practice Questions (WooClap!)

# Spirometry: Volumes (i)

- **TV** = tidal volume
- **IRV** = inspiratory reserve volume
- **ERV** = expiratory reserve volume
- **RV** = residual volume\*

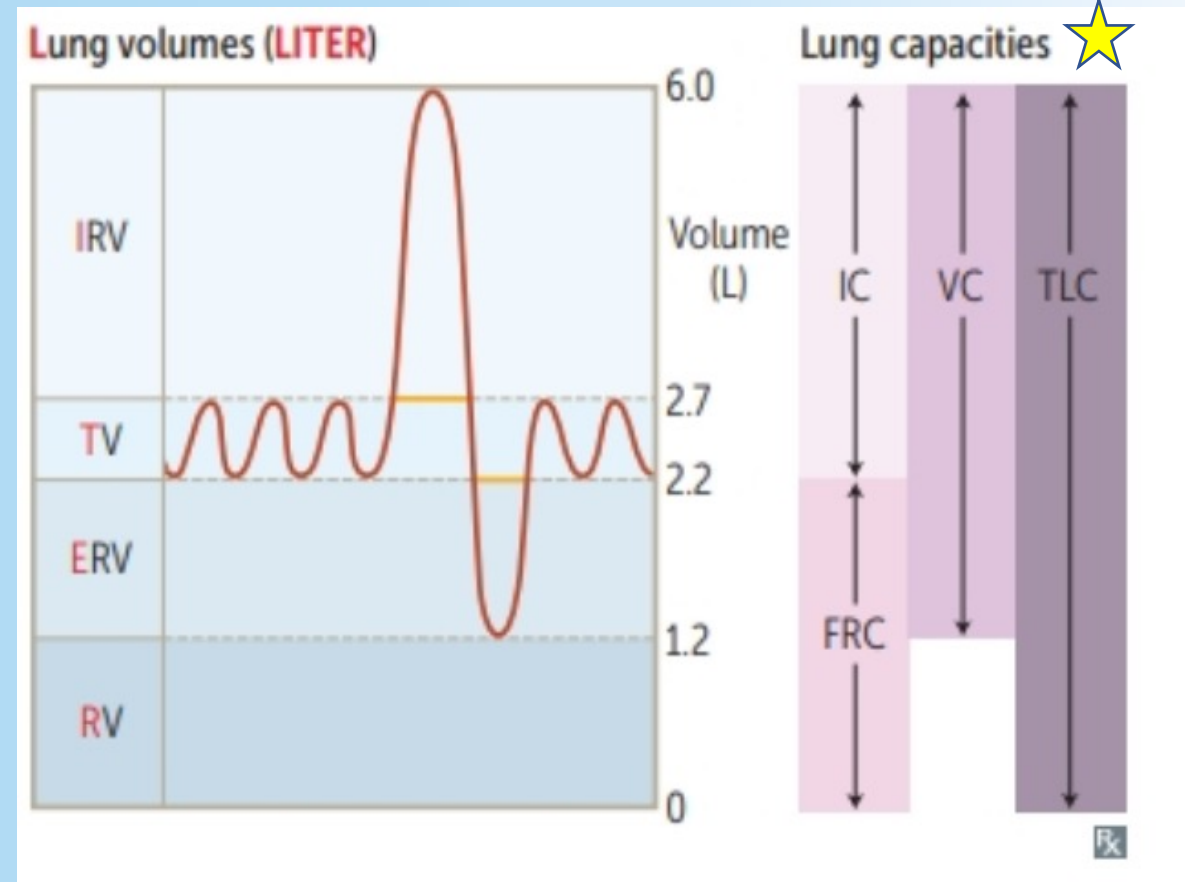
\*RV = Air that is left in the lungs after maximal expiration. Cannot be measured with spirometry.



★ \* It is important to know all these definitions (volumes and capacities) for your midterm.

# Spirometry: Capacities (ii)

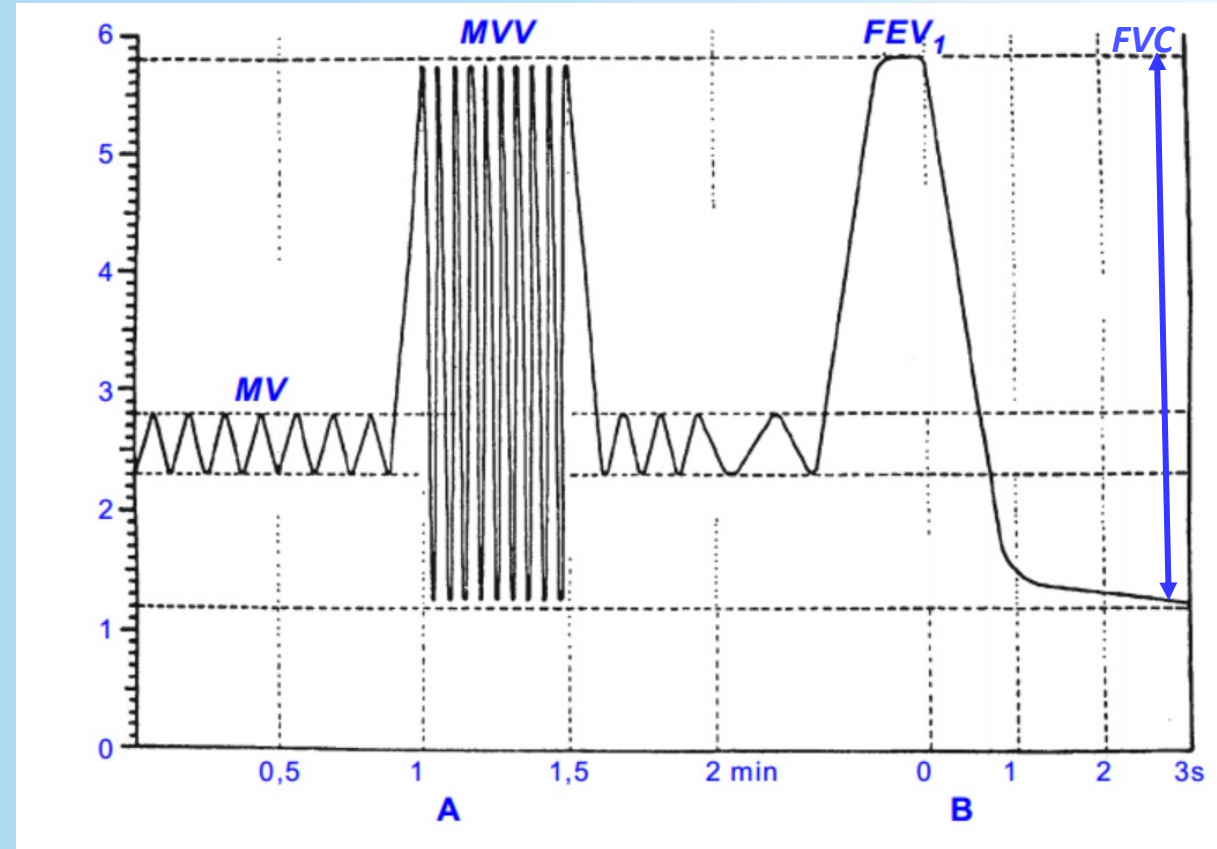
- **Volume vs Capacities:** A capacity is the sum of  $\geq 2$  lung volumes
- **Vital capacity (VC):** volume of air that can be forcefully expired after max inspiration
- **Total lung capacity (TLC):** vital capacity + residual volume



*\* It is important to know all these definitions (volumes and capacities) for your midterm.*

# Spirometry: Other Measures (ii)

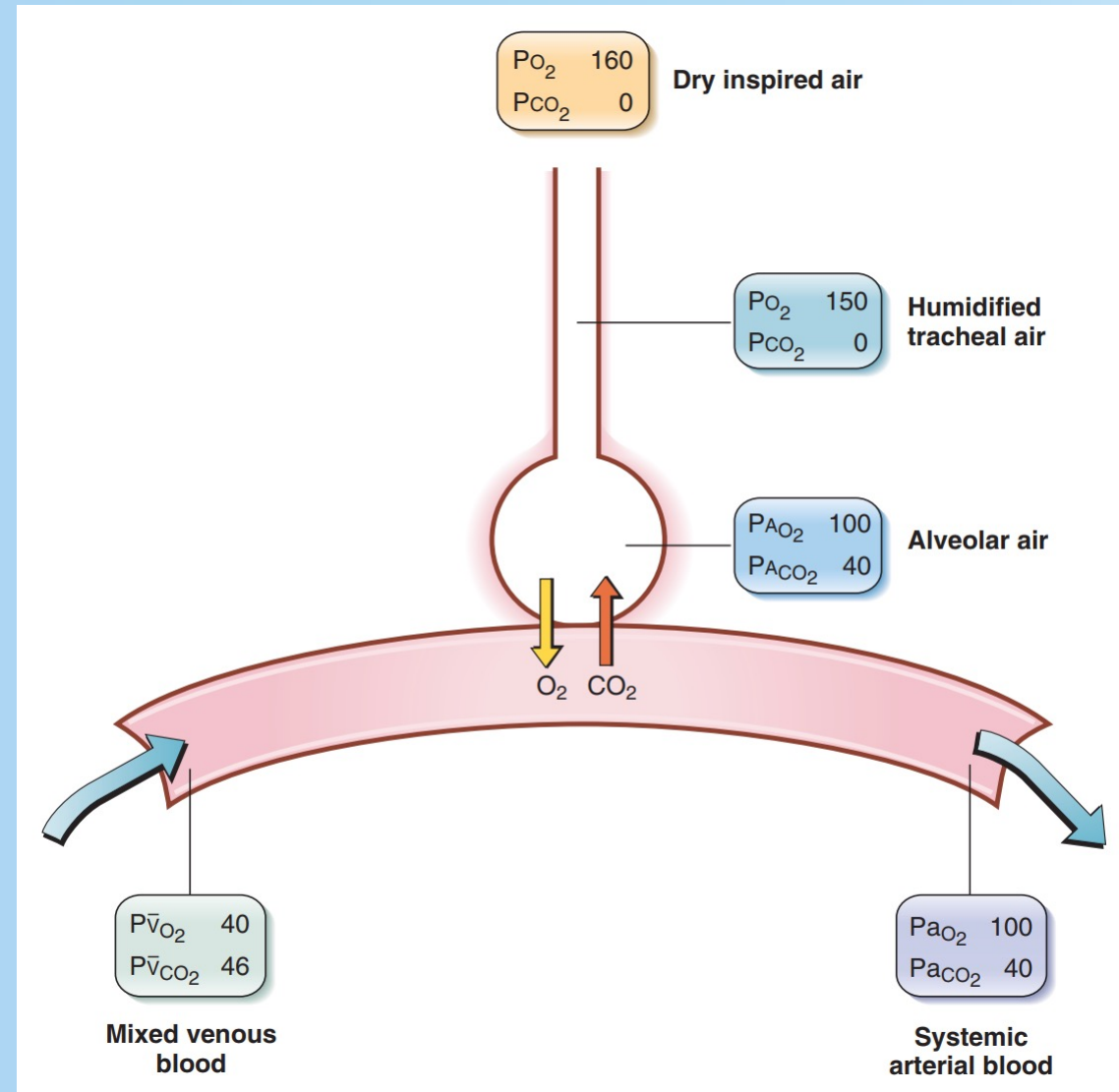
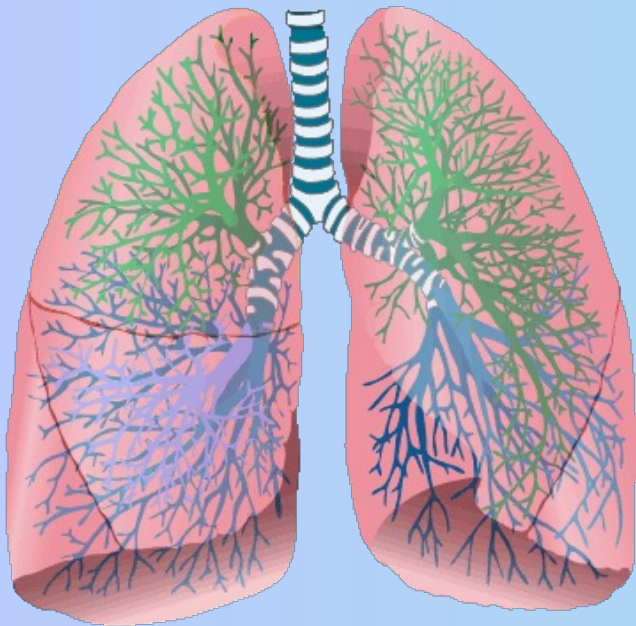
- **MVV (maximal voluntary ventilation):** total volume of air that can be exhaled during 12 seconds of deep breathing
- ★ • **FEV<sub>1</sub> (forced expiratory volume, during first second):** Volume that has been exhaled by the end of the first second of forced expiration
- The **FEV<sub>1</sub> / FVC ratio** is also used for diagnostic purposes (normal ~70%)



# Outline

- ~~Ventilation vs Respiration~~
- ~~“Dead space”, “Alveolar”, and “Minute”-ventilation~~
- ~~Primary & Accessory muscles of respiration~~
- ★ • ~~Respiratory system pressures (alveolar, intrapleural, transpulmonary)~~
- ~~Clinical application: Pneumothorax~~
- ~~Role of surfactant~~
- ~~Spirometry~~
- Gas Exchange (basics)
- Practice Questions (WooClap!)

# Basics of Gas Exchange: External Respiration



# How to participate?



**WEB**

- 1 Connect to [www.wooclap.com/BREATHMEC](http://www.wooclap.com/BREATHMEC)
- 2 You can participate

