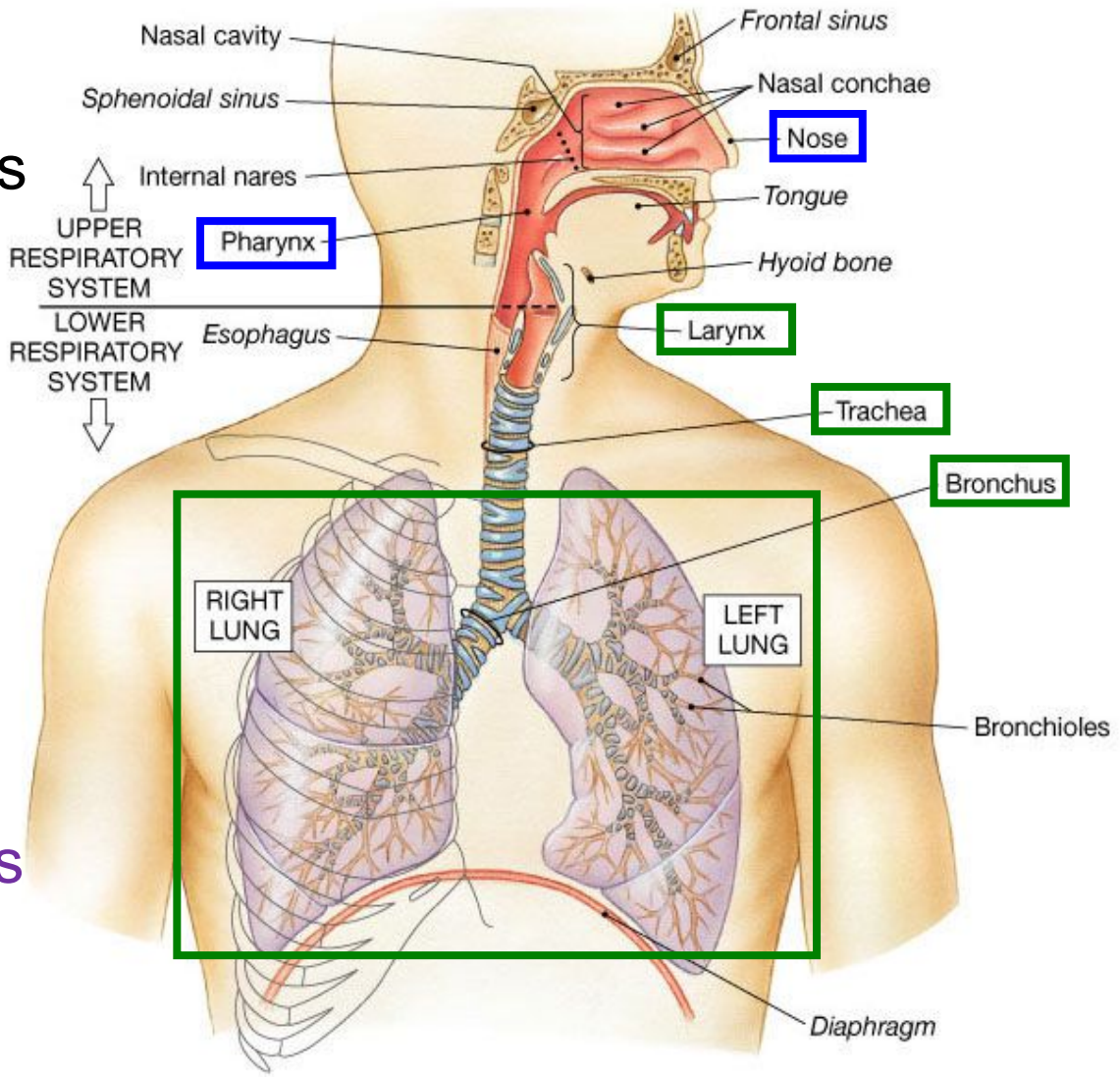
Introduction to the Mechanism of Breathing & Ventilation

Dr. Denny C.W. Ma

Components of the Respiratory System

- Upper Tract
  - Nose, pharynx & associated structures
  - Filter & humidify incoming air
- Lower Tract
  - Larynx, trachea, bronchi & lungs
  - Include delicate conduction passages & gas exchange surfaces (alveoli)



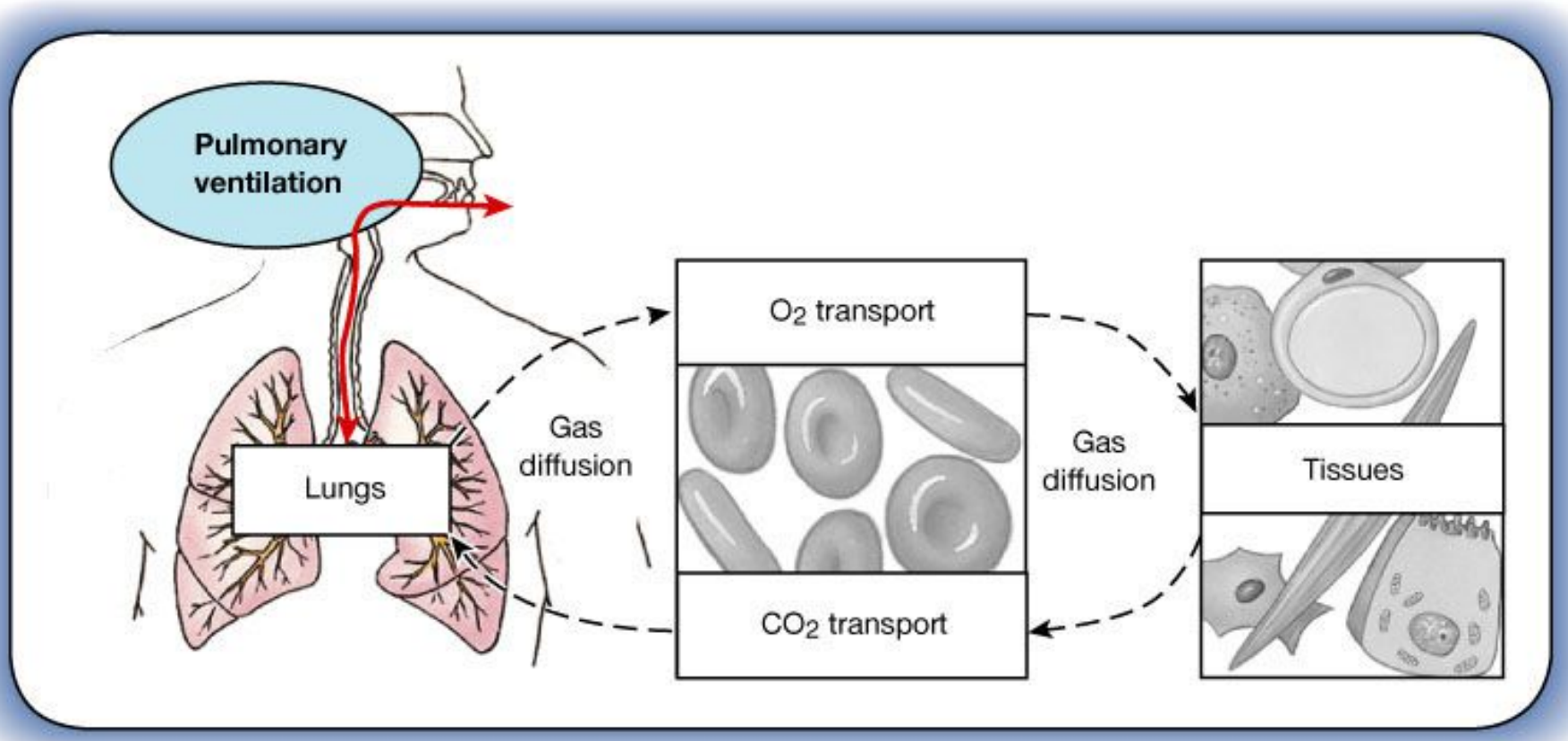
Processes in Respiration

- To supply the body with oxygen & dispose of carbon dioxide

- Respiration involves 4 distinct processes:
  1. **Pulmonary ventilation** – movement of air into & out of **lungs**
  2. **External respiration** – gas exchange between **lungs** & **blood**
  3. **Transport** – transport of O_2 & CO_2 between **lungs** & **tissues**
  4. **Internal respiration** – gas exchange between systemic **blood** vessels & **tissues**

Pulmonary Ventilation

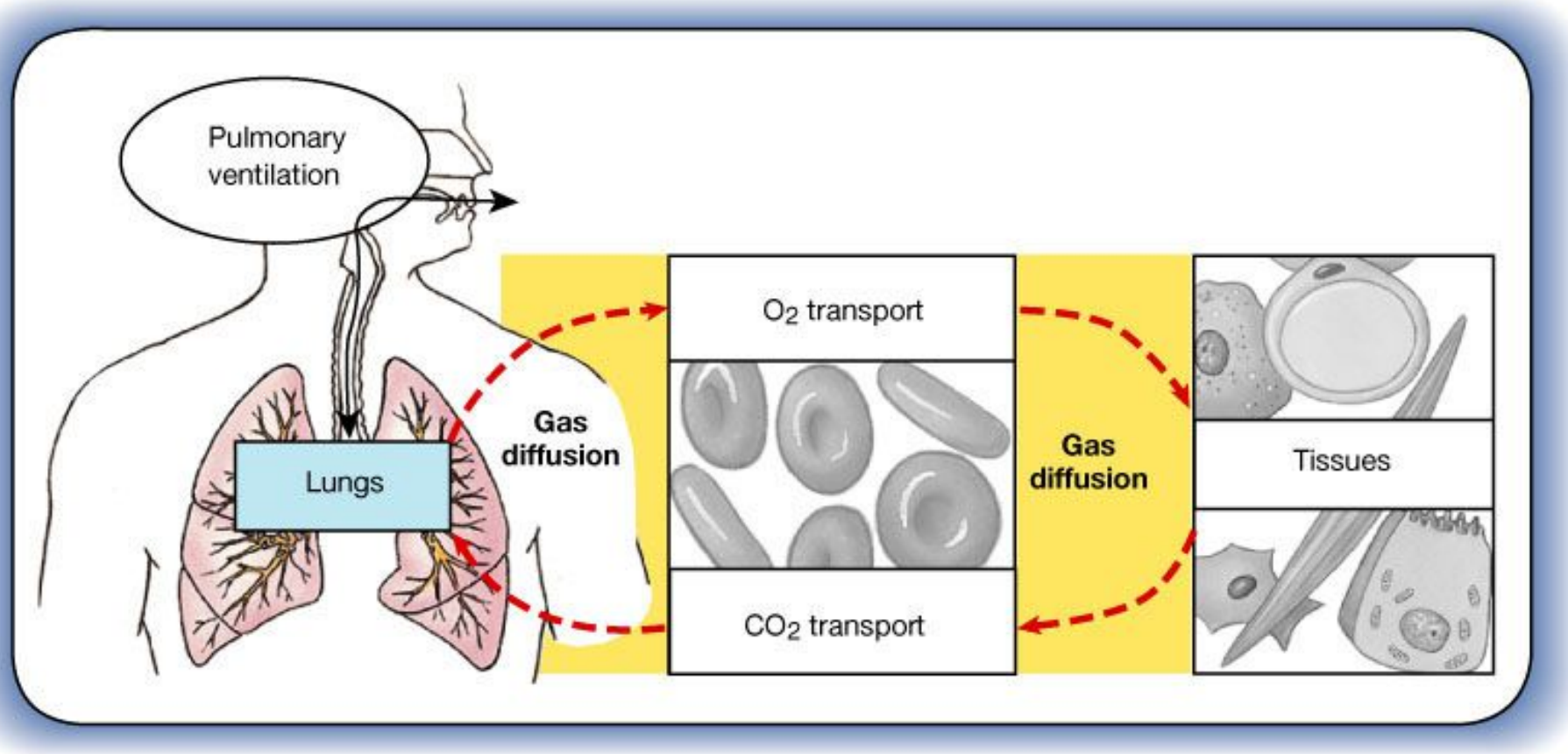
Movement of air into & out of **lungs**



External Respiration & Internal Respiration

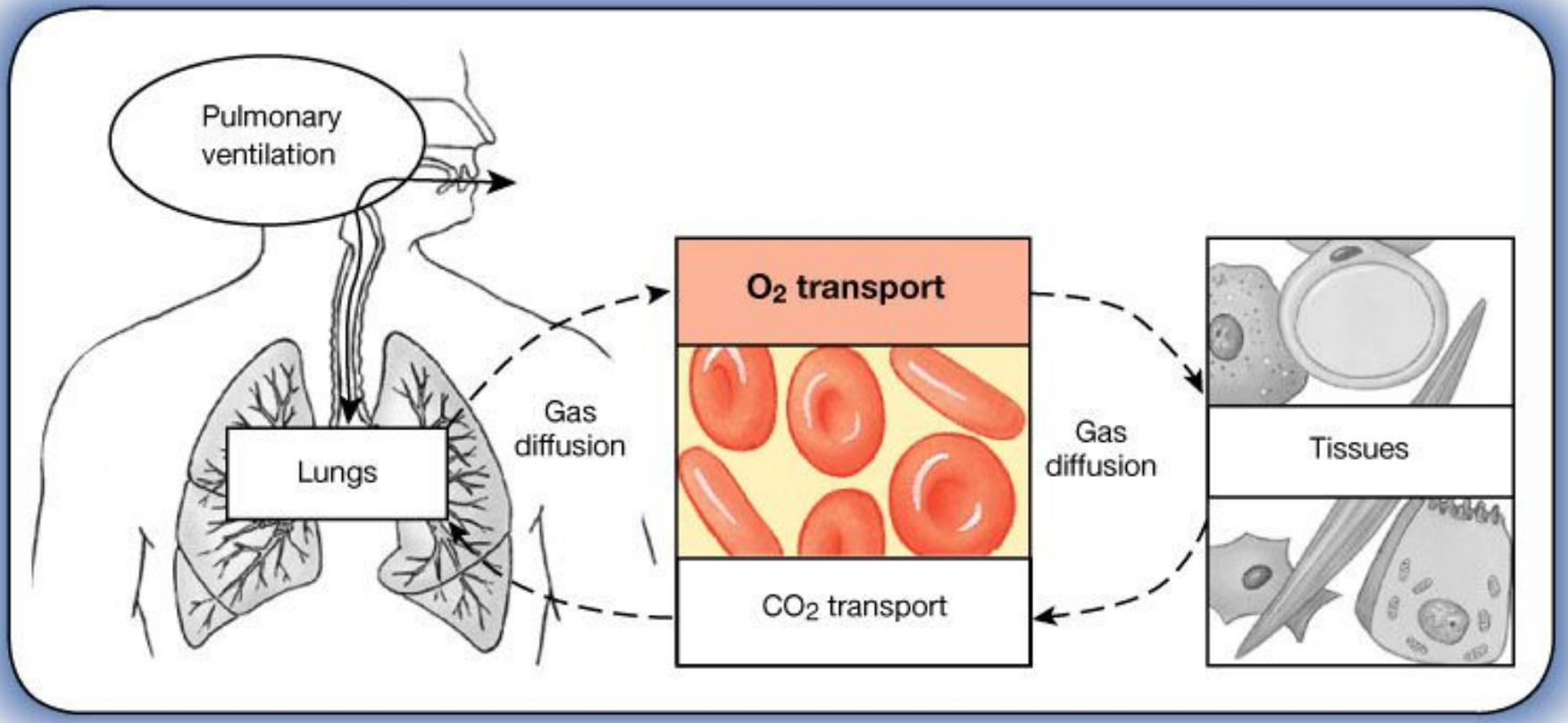
Gas exchange between **lungs** & **blood**

Gas exchange between systemic **blood** vessels & **tissues**



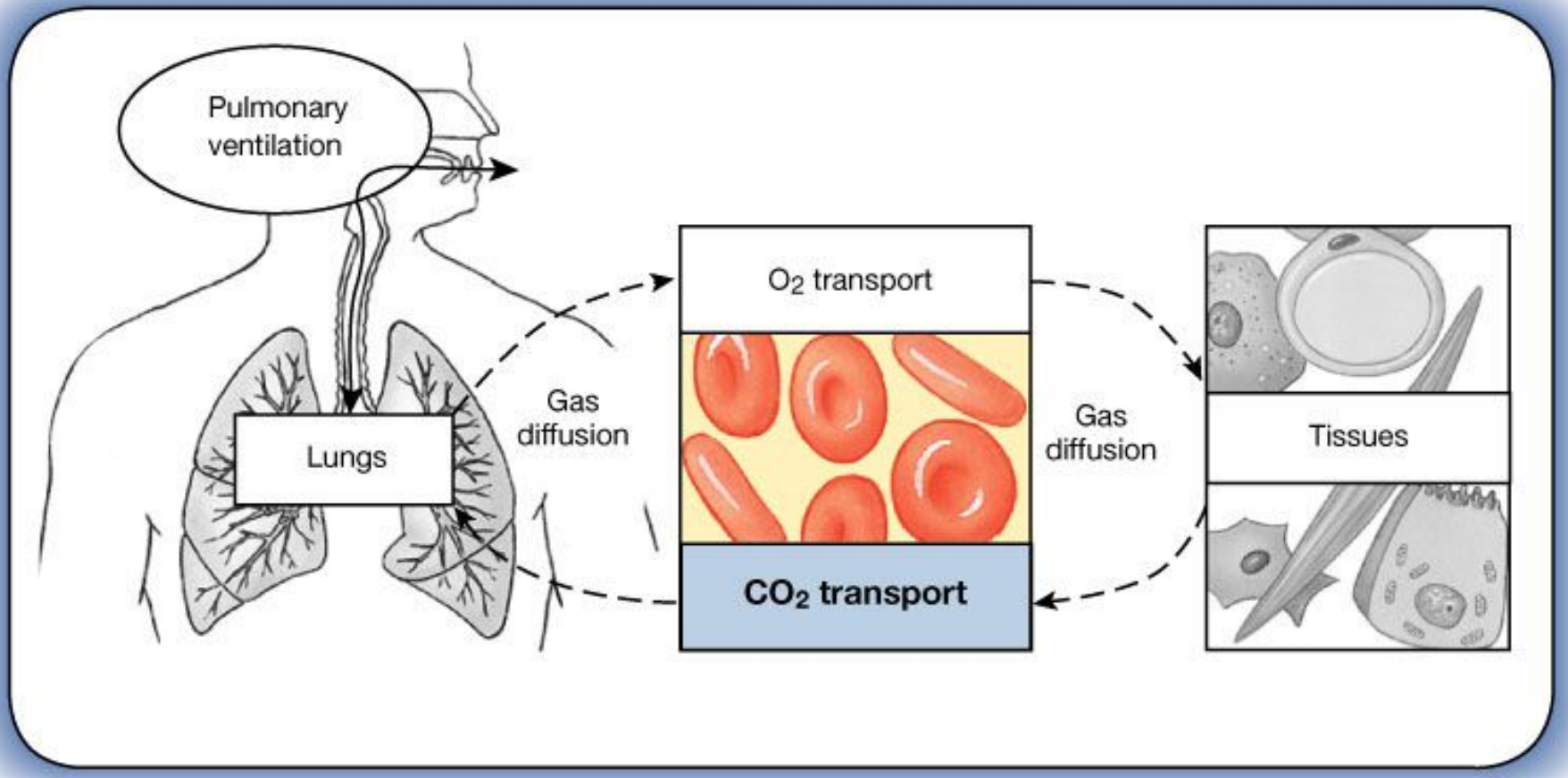
Transport (Oxygen)

Transport of O_2 from **lungs** to **tissues**



Transport (Carbon Dioxide)

Transport of CO_2 from **tissues** to **lungs**



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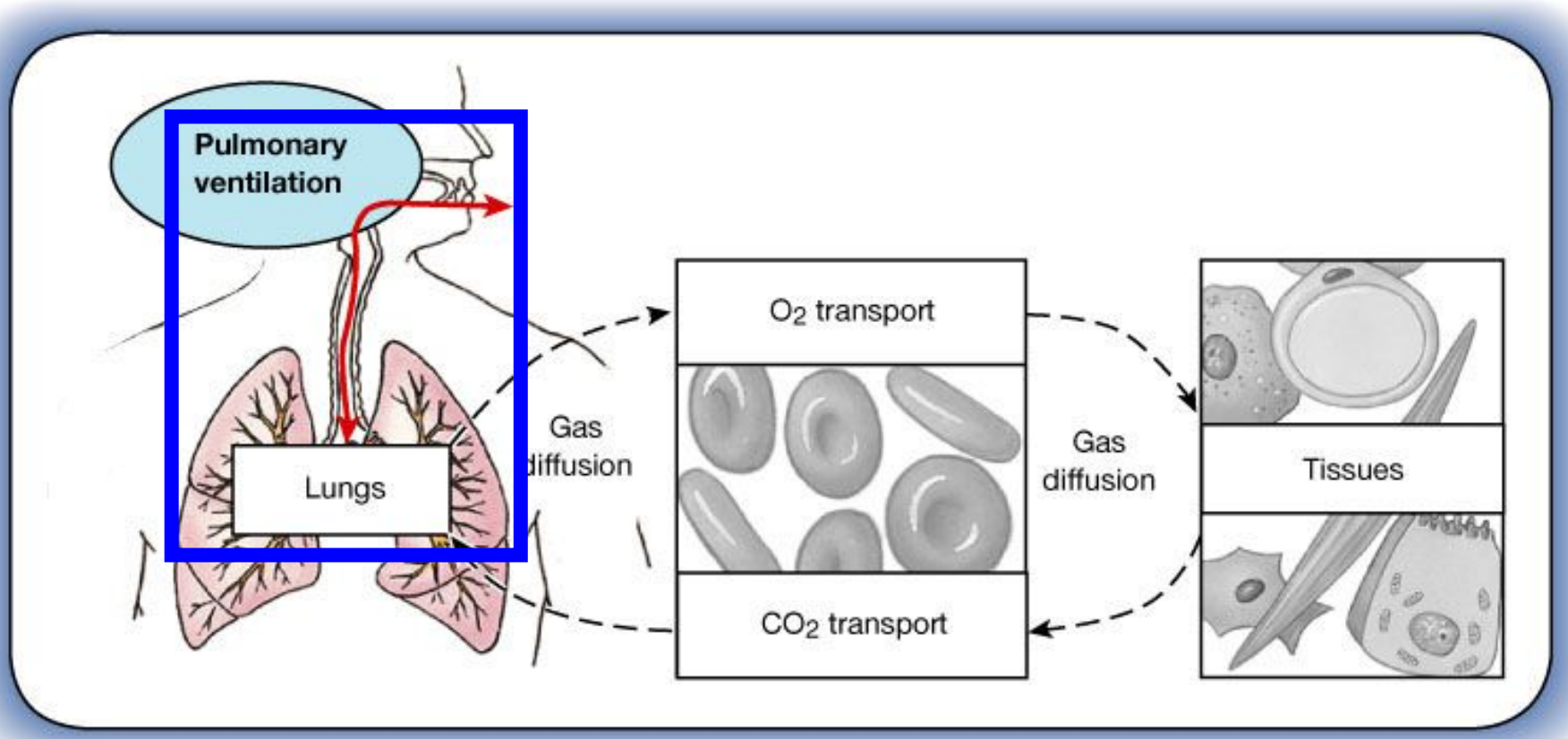
Pulmonary Ventilation

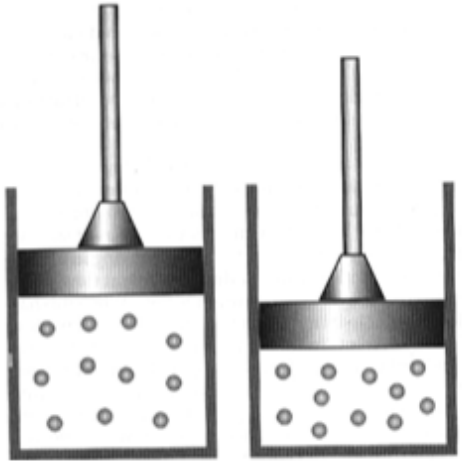


Two phases:

- Inspiration – air flows into lungs
- Expiration – gases exit lungs

Boyle's Law

Pressure (P) of a gas varies inversely with its volume (V)
(when temperature (T) is constant)



Breathing

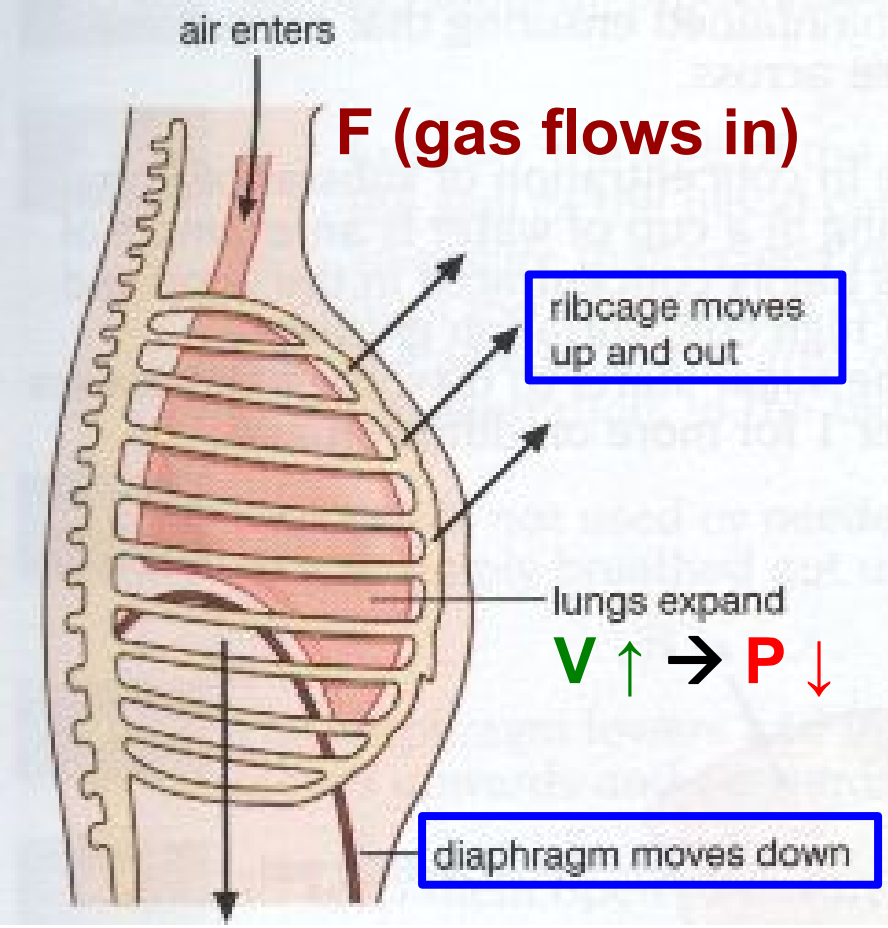
Volume change → Pressure change → Flow of gases

ΔV → ΔP → U

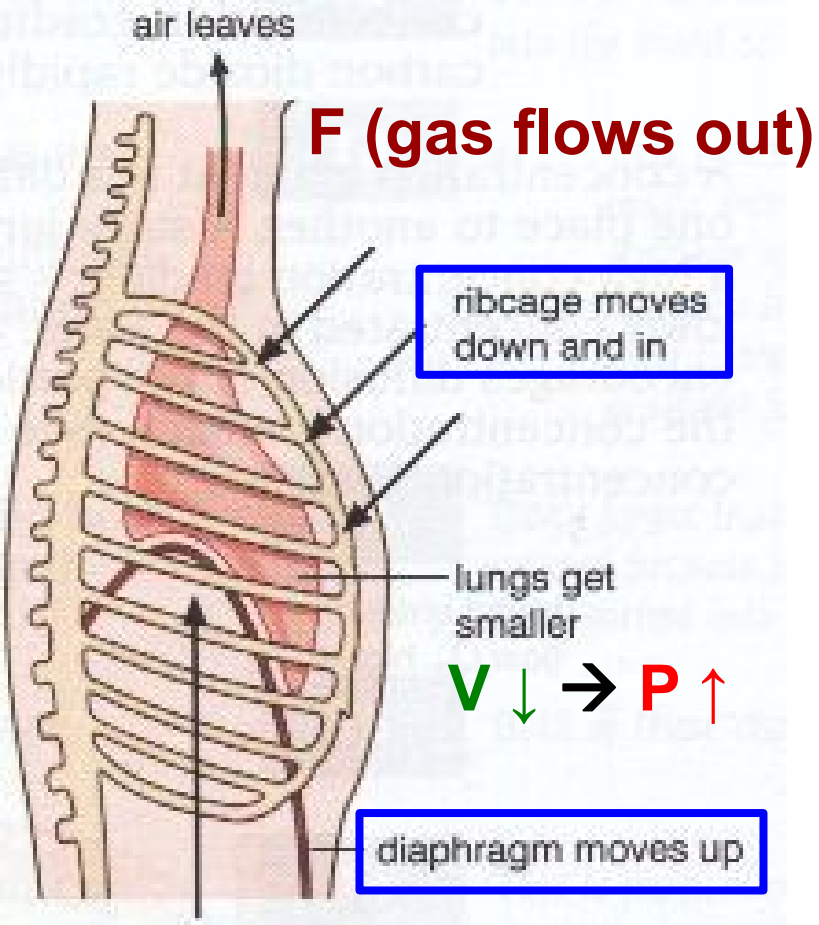
Thoracic cavity

Lung ← → Atmosphere

Inspiration & Expiration



Inspiration



Expiration

Volume change depends on movement of diaphragm & ribs

between thoracic & abdominal cavities

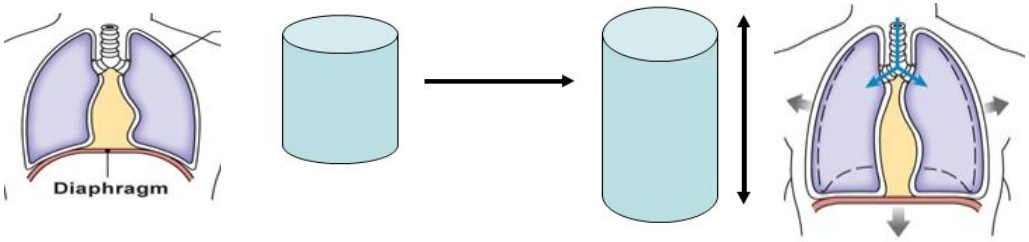
Inspiration

Action of diaphragm:

Dome-shaped diaphragm contracts, moves inferiorly & flattens out

→ Superior-inferior dimension of thoracic cavity increases

Relax



Contract

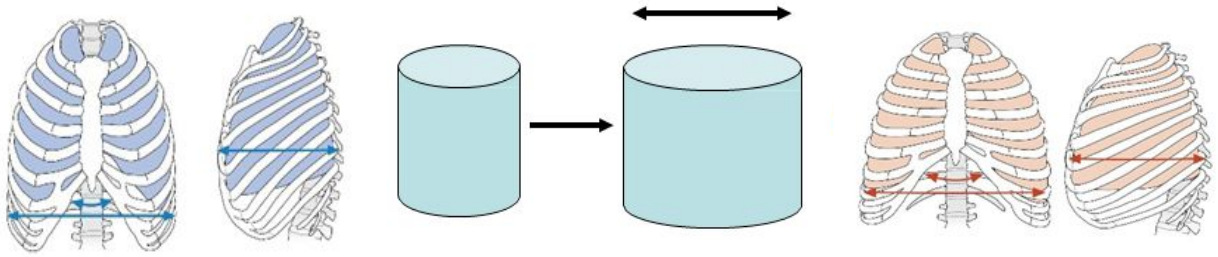
Action of intercostal muscle:

External intercostal muscles contracts

→ Rib cage is elevated & sternum is pulled forward

→ Circumference of thoracic cavity increases

Relax



Contract

Inspiration

Lungs are stretched & intrapulmonary volume increases

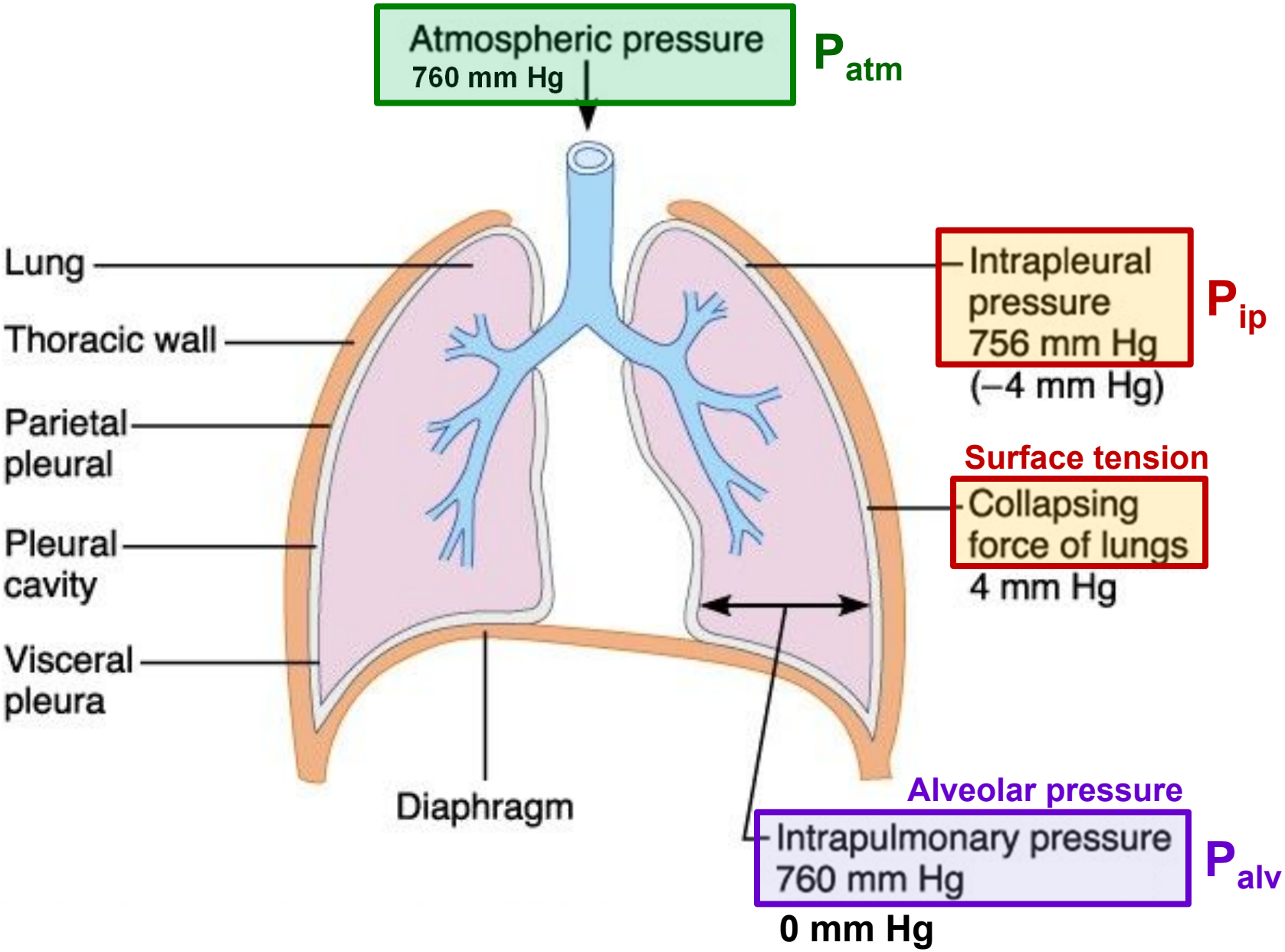
→ Intrapulmonary pressure drops (to –1 mm Hg)

[below atmospheric pressure (0 mm Hg)]

→ Air flows into lungs down pressure gradient

[until intrapulmonary pressure = atmospheric pressure = 0]

Inspiration

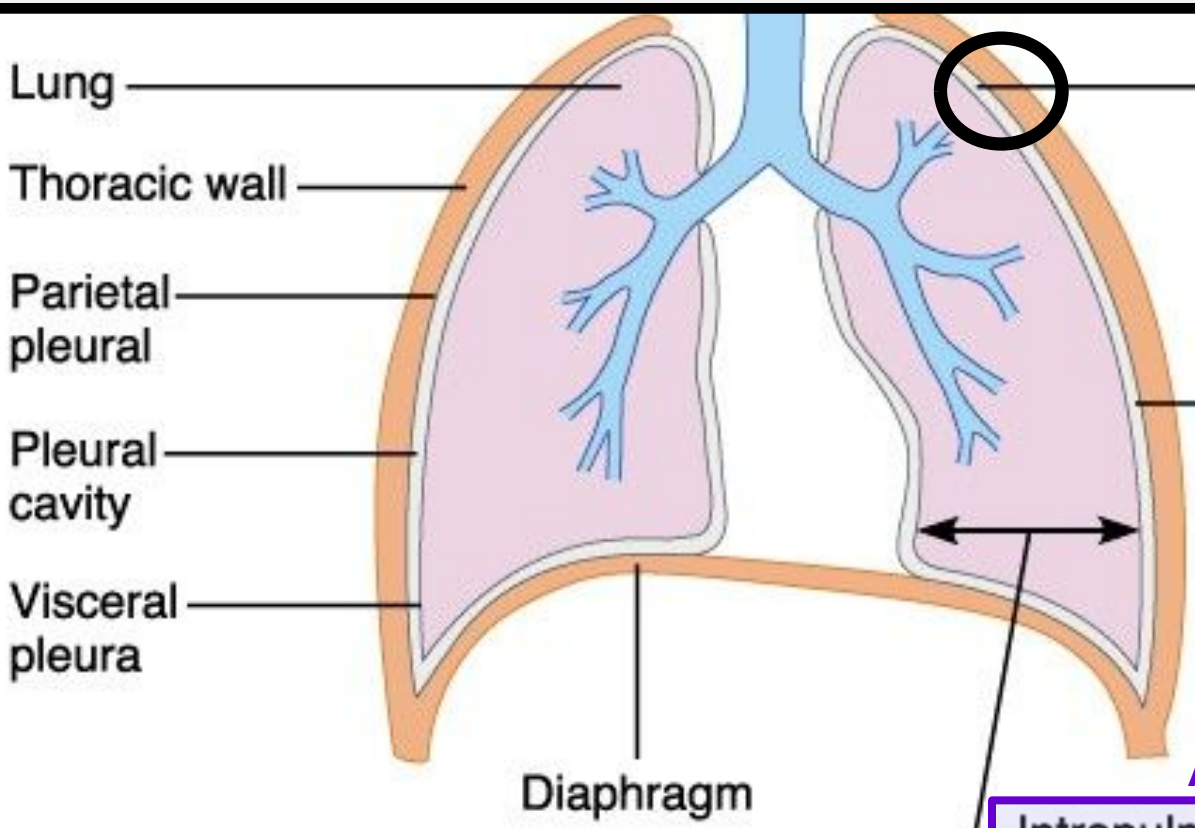


Inspiration

Lungs can slide but not separated from pleura

→ Lungs adhere to thoracic wall

→ Expand/recoil as thoracic cavity changes in volume during breathing



Intrapleural pressure
756 mm Hg
(–4 mm Hg)

P_{ip}

Surface tension

Collapsing force of lungs
4 mm Hg

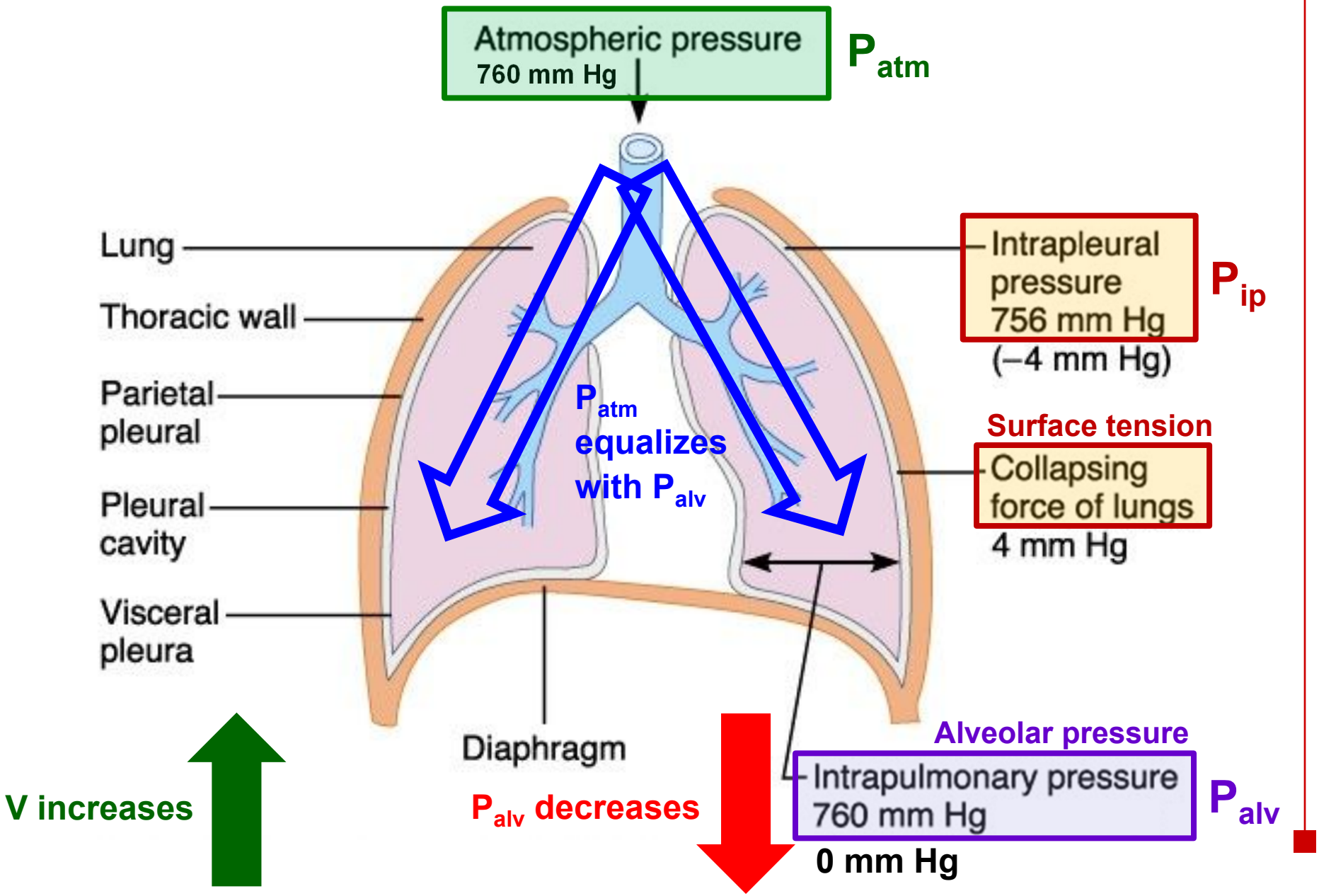
Alveolar pressure

Intrapulmonary pressure
760 mm Hg

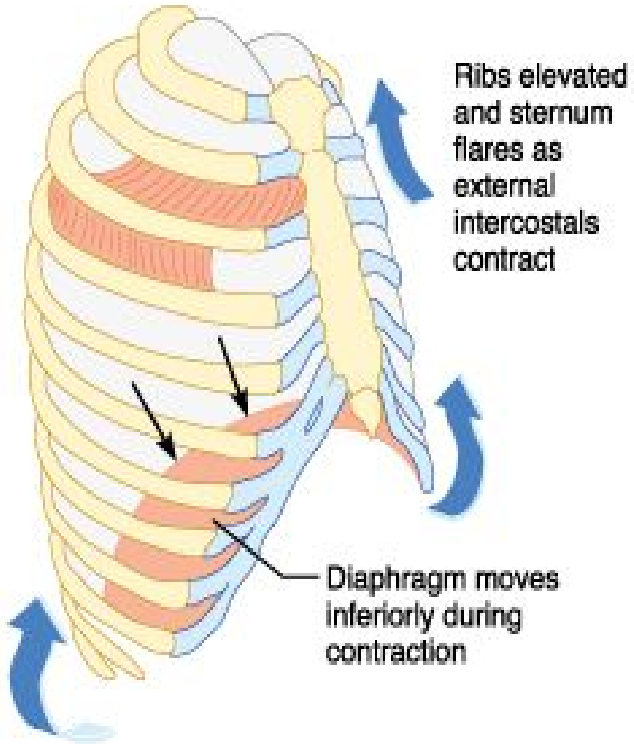
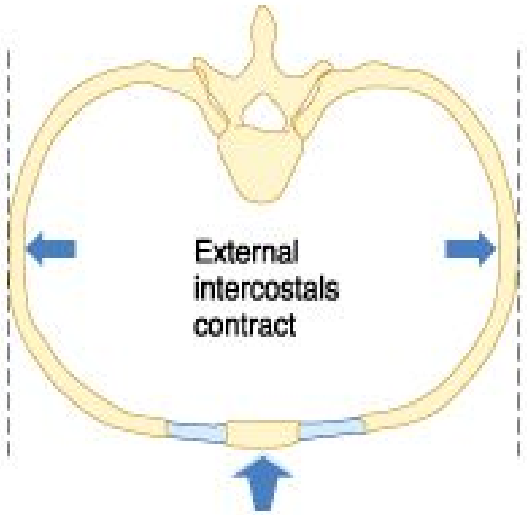
P_{alv}

0 mm Hg

Inspiration



Inspiration

	Sequence of events	Changes in anterior-posterior and superior-inferior dimensions	Changes in lateral dimensions
Inspiration	① Inspiratory muscles contract (diaphragm descends; rib cage rises) ↓ ② Thoracic cavity volume increases ↓ ③ Lungs stretched; intrapulmonary volume increases ↓ ④ Intrapulmonary pressure drops (to −1 mm Hg) ↓ ⑤ Air (gases) flows into lungs down its pressure gradient until intrapulmonary pressure is 0 (equal to atmospheric pressure)		

Expiration

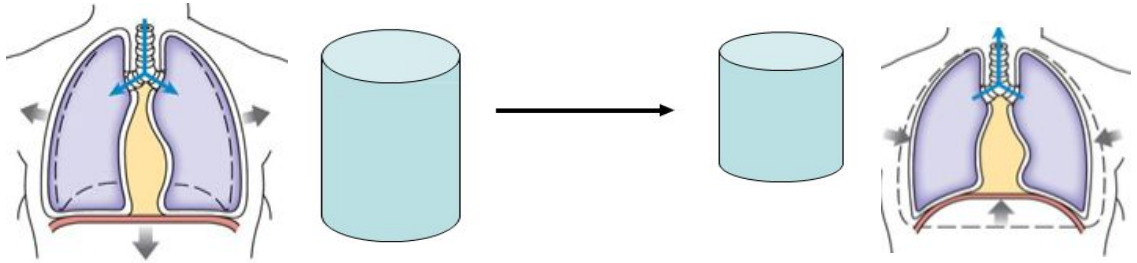
Quiet expiration depends on natural elasticity of lungs (instead of muscle contraction)

Inspiratory muscles relax & resume resting length

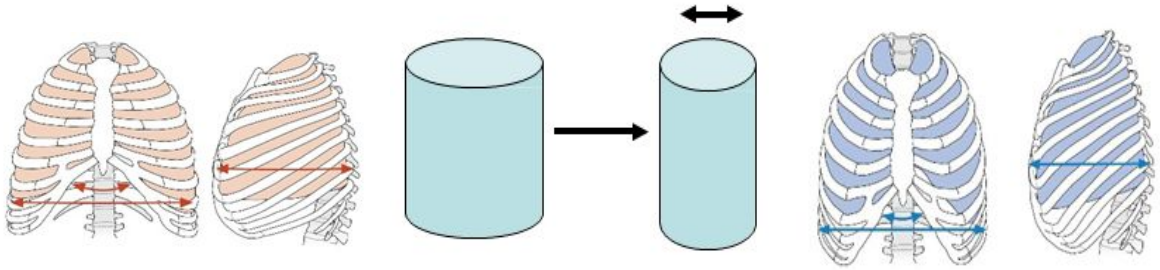
→ Rib cage descends (due to gravity)

→ Volume of thoracic cavity decreases

→ Lungs recoil



Contract **Relax**



Expiration

Intrapulmonary volumes decreases

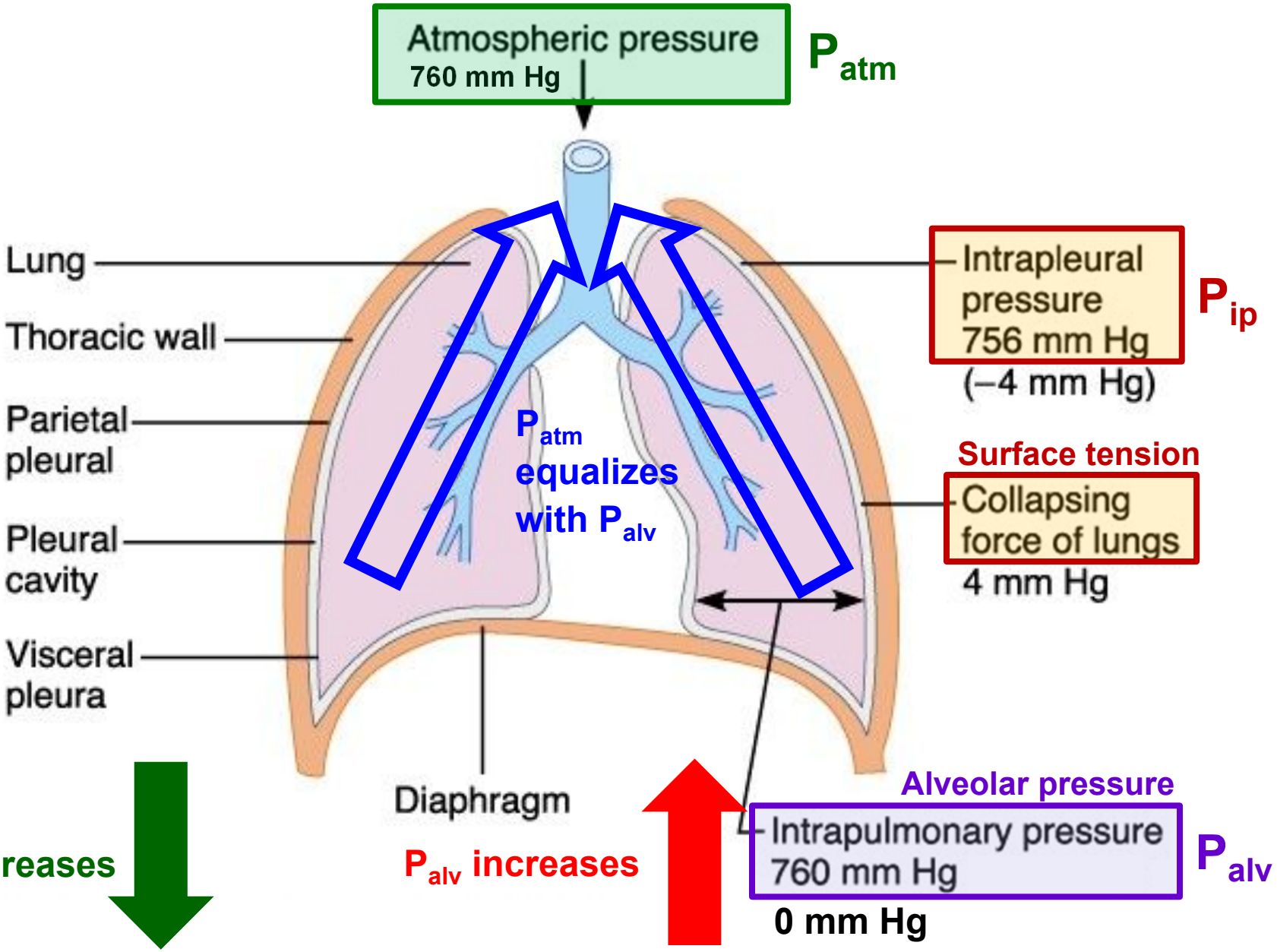
→ Intrapulmonary pressure rises (to +1 mm Hg)

[above atmospheric pressure (0 mm Hg)]

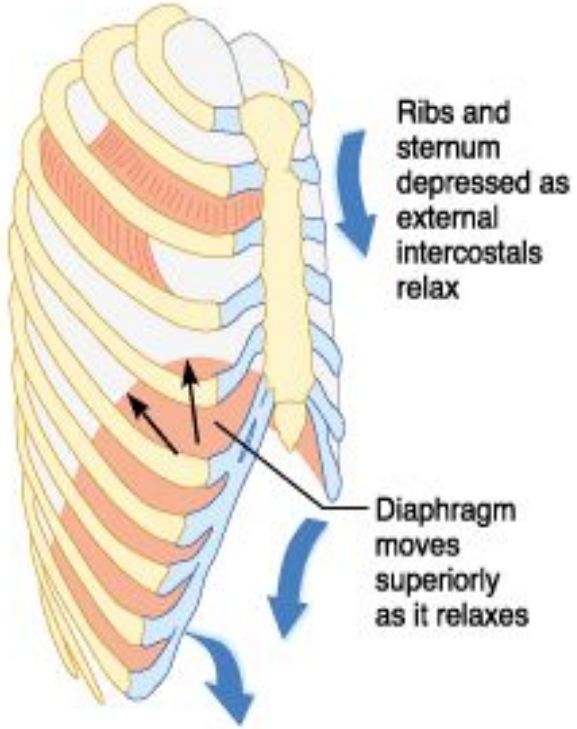
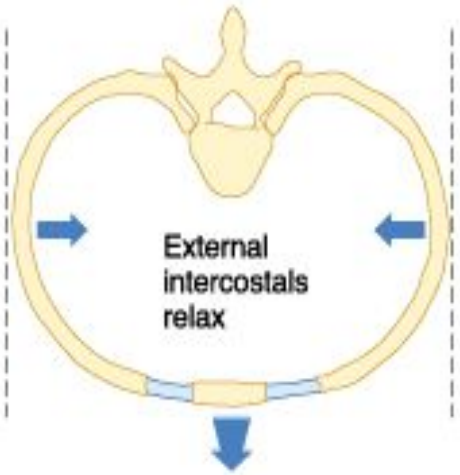
→ Gases flow out of lungs down pressure gradient

[until intrapulmonary pressure = atmospheric pressure = 0]

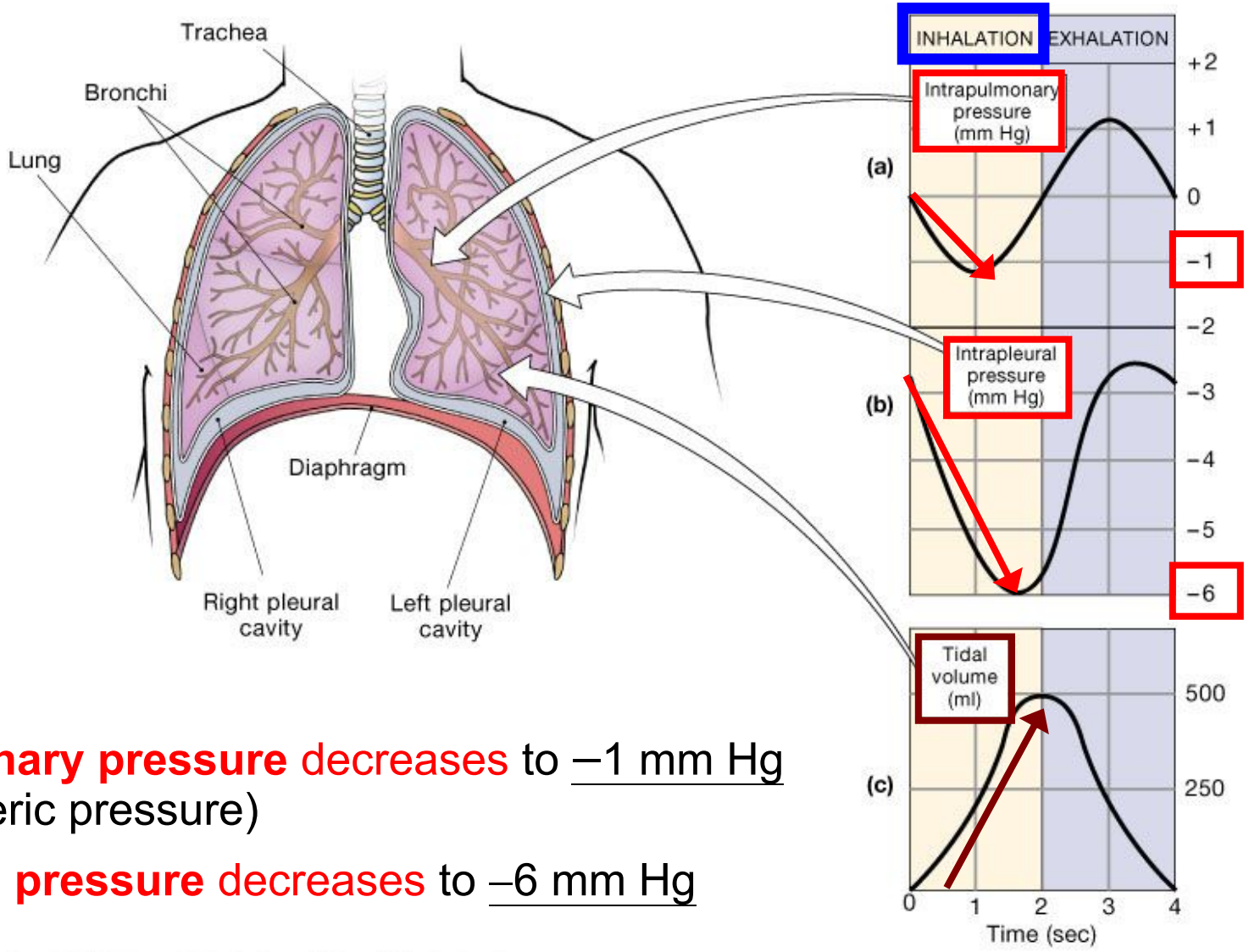
Expiration


Atmospheric pressure
760 mm Hg
P_{atm}
Lung
Thoracic wall
Parietal pleural
Pleural cavity
Visceral pleura
Diaphragm
Intrapleural pressure
756 mm Hg
(–4 mm Hg)
P_{ip}
P_{atm} equalizes with P_{alv}
Surface tension
Collapsing force of lungs
4 mm Hg
Alveolar pressure
Intrapulmonary pressure
760 mm Hg
P_{alv}
0 mm Hg
V decreases
P_{alv} increases

Expiration

	Sequence of events	Changes in anterior-posterior and superior-inferior dimensions	Changes in lateral dimensions
Expiration	① Inspiratory muscles relax (diaphragm rises; rib cage descends due to gravity) ↓ ② Thoracic cavity volume decreases ↓ ③ Elastic lungs recoil passively; intrapulmonary volume decreases ↓ ④ Intrapulmonary pressure rises (to +1 mm Hg) ↓ ⑤ Air (gases) flows out of lungs down its pressure gradient until intrapulmonary pressure is 0		

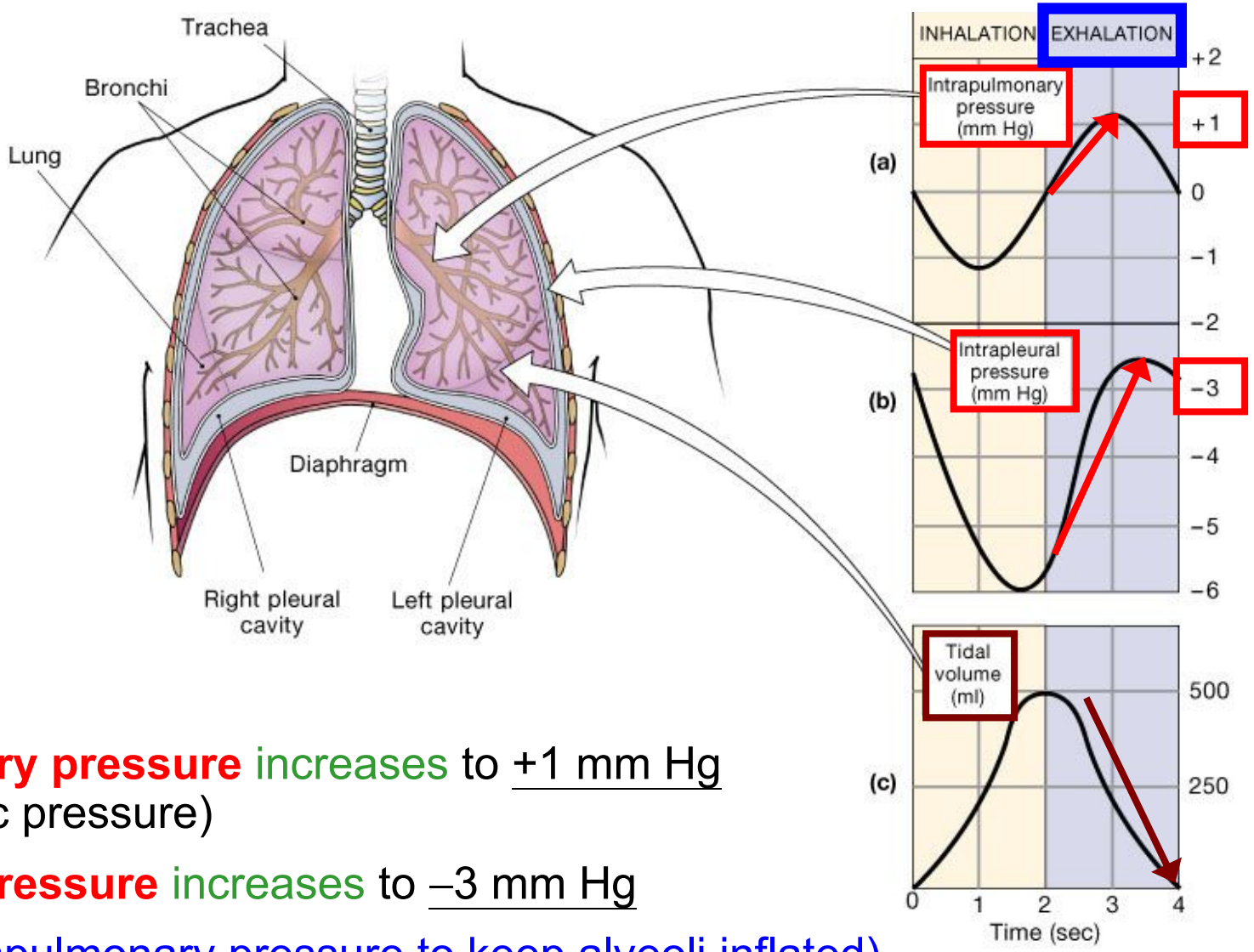
Pressure & Volume Changes during Inspiration



Intrapulmonary pressure decreases to –1 mm Hg (< atmospheric pressure)

Intrapleural pressure decreases to –6 mm Hg

Pressure & Volume Changes during Expiration



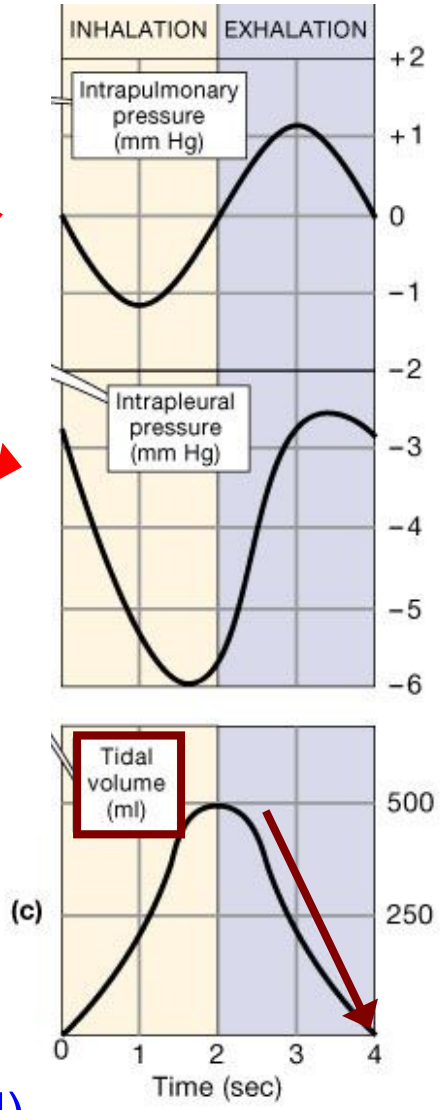
Intrapulmonary pressure increases to +1 mm Hg
(> atmospheric pressure)

Intrapleural pressure increases to –3 mm Hg

(but still < intrapulmonary pressure to keep alveoli inflated)

Pressure & Volume Changes during Expiration

Intrapulmonary pressure
is always higher than
intrapleural pressure



Intrapulmonary pressure increases to +1 mm Hg
(> atmospheric pressure)

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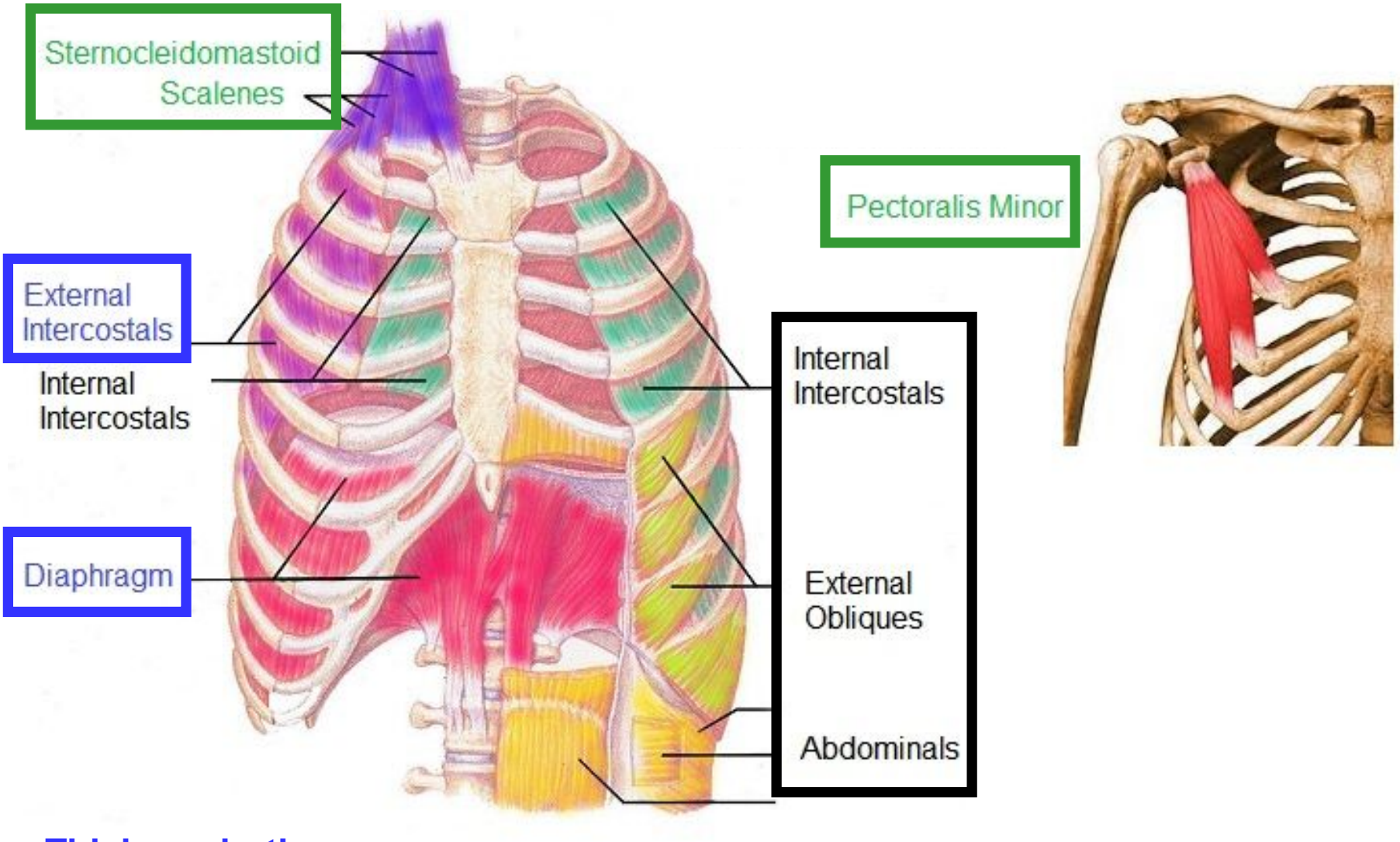
(but still < intrapulmonary pressure to keep alveoli inflated)

Forced Inhalation & Expiration



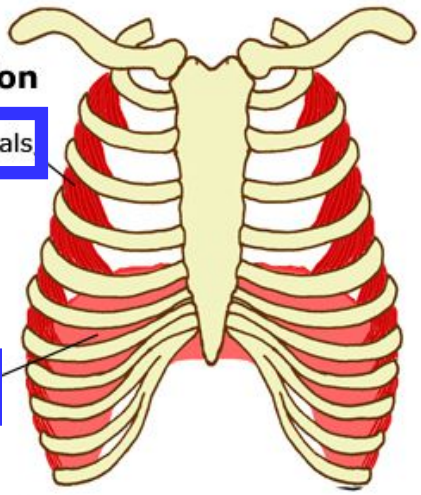
Tidal respiration

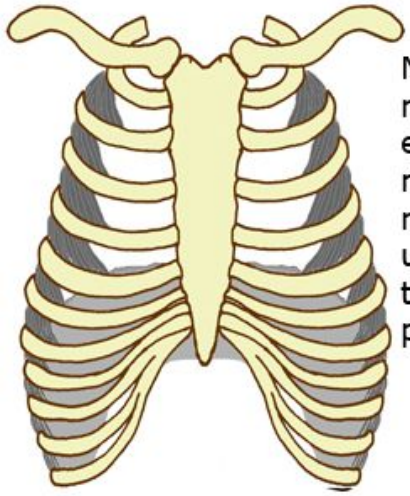
Forced inhalation

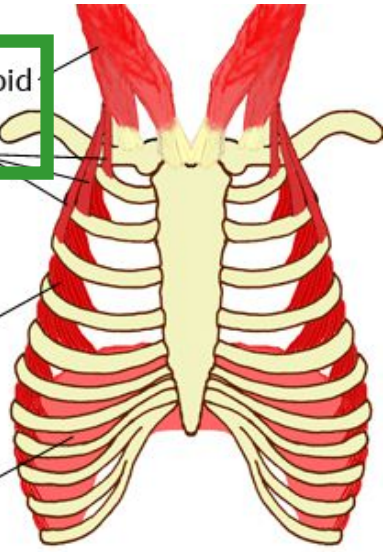
Forced expiration

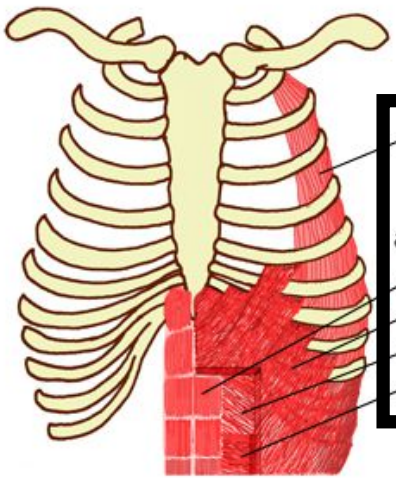
Forced Inhalation & Expiration

	Inspiration	Expiration
Tidal	**Muscles of relaxed inhalation** external intercostals diaphragm	**Relaxed exhalation** No muscles are required for exhalation - muscles of inhalation relax and tissues undergo "elastic recoil" to their original position.
Forced	**Muscles of forced inhalation** sternocleidomastoid scalene muscles external intercostals diaphragm	**Muscles of forced exhalation** internal intercostals abdominal muscles rectus abdominis external obliques internal obliques transversus abdominis

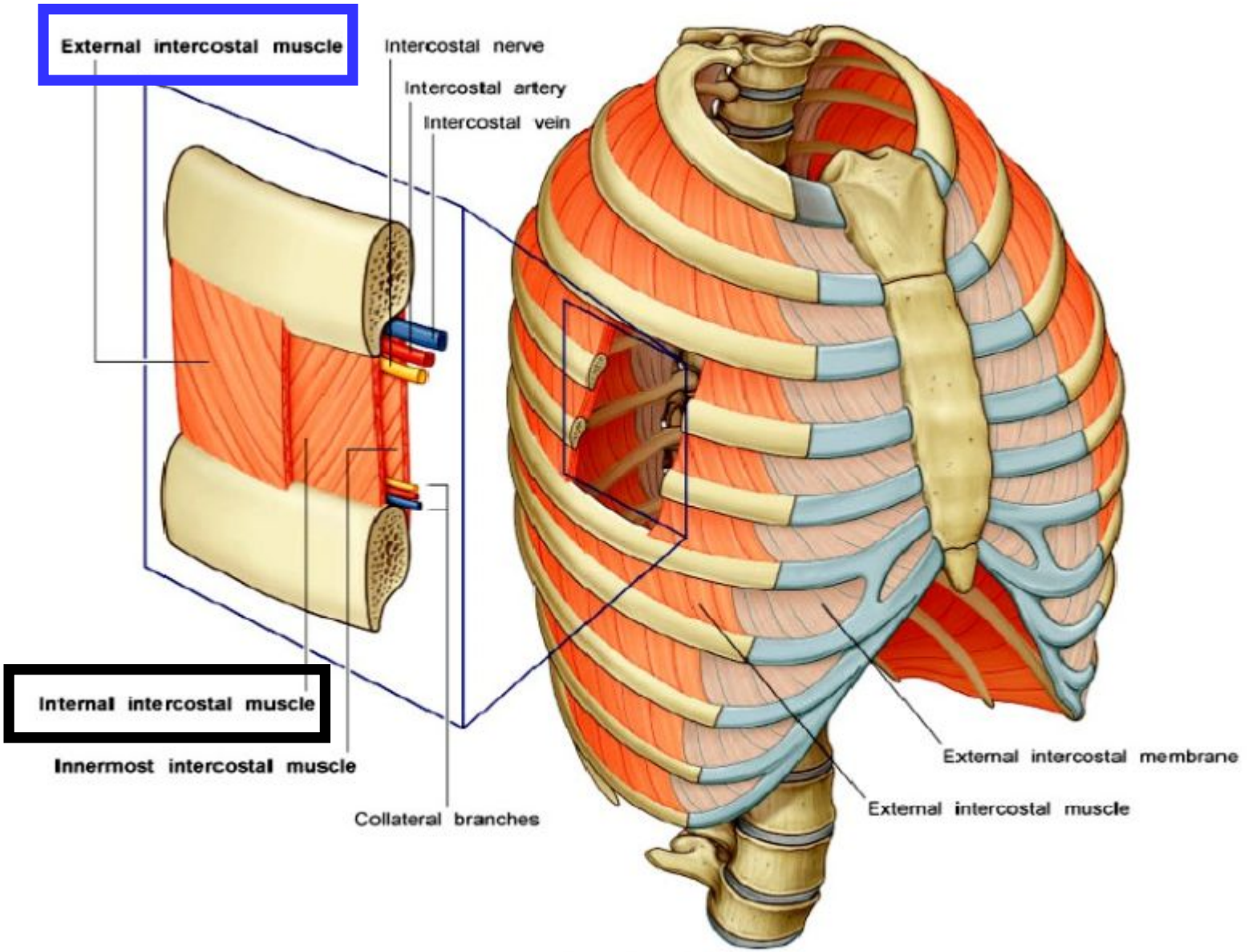




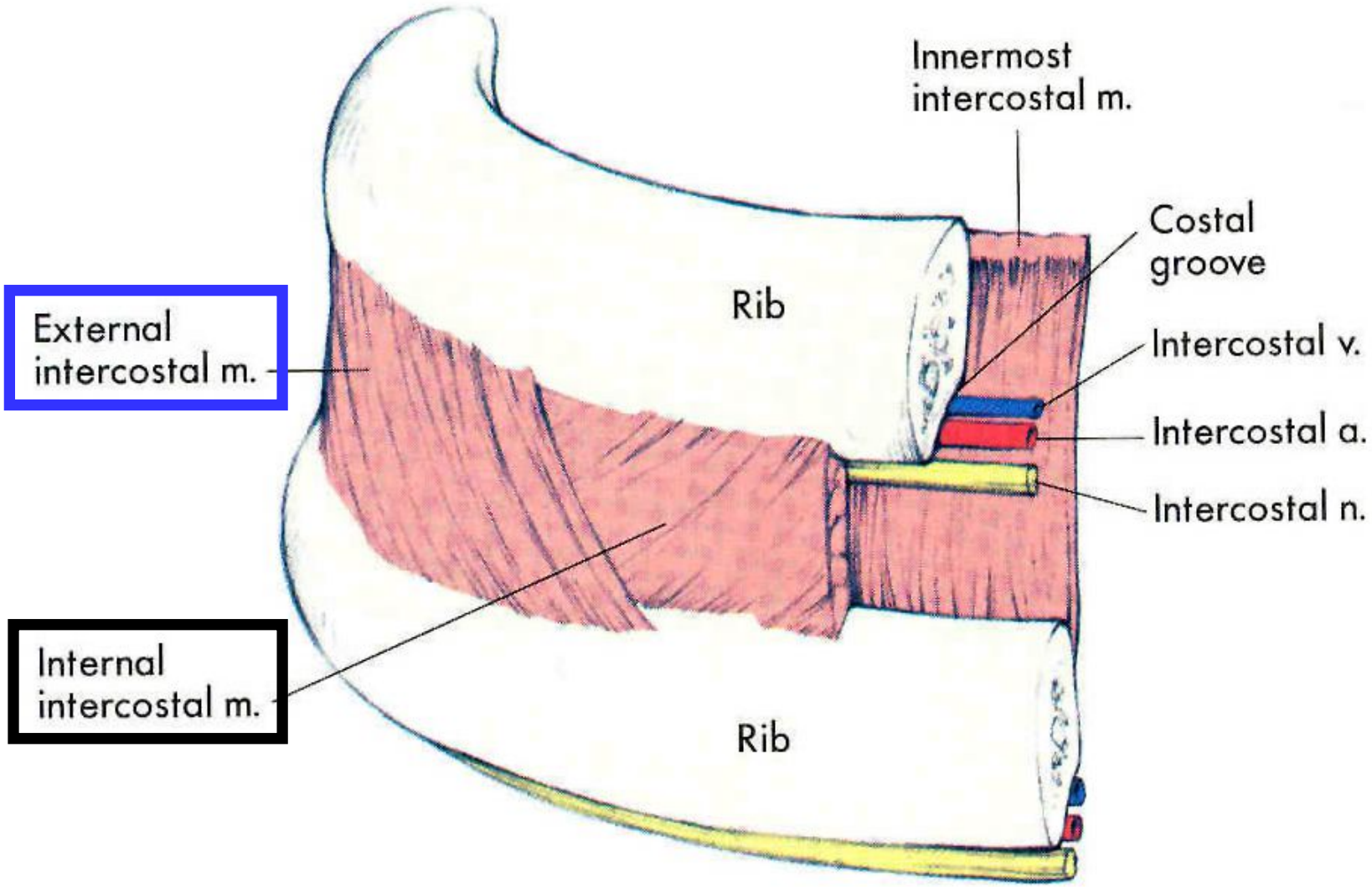




External & Internal Intercostal Muscles



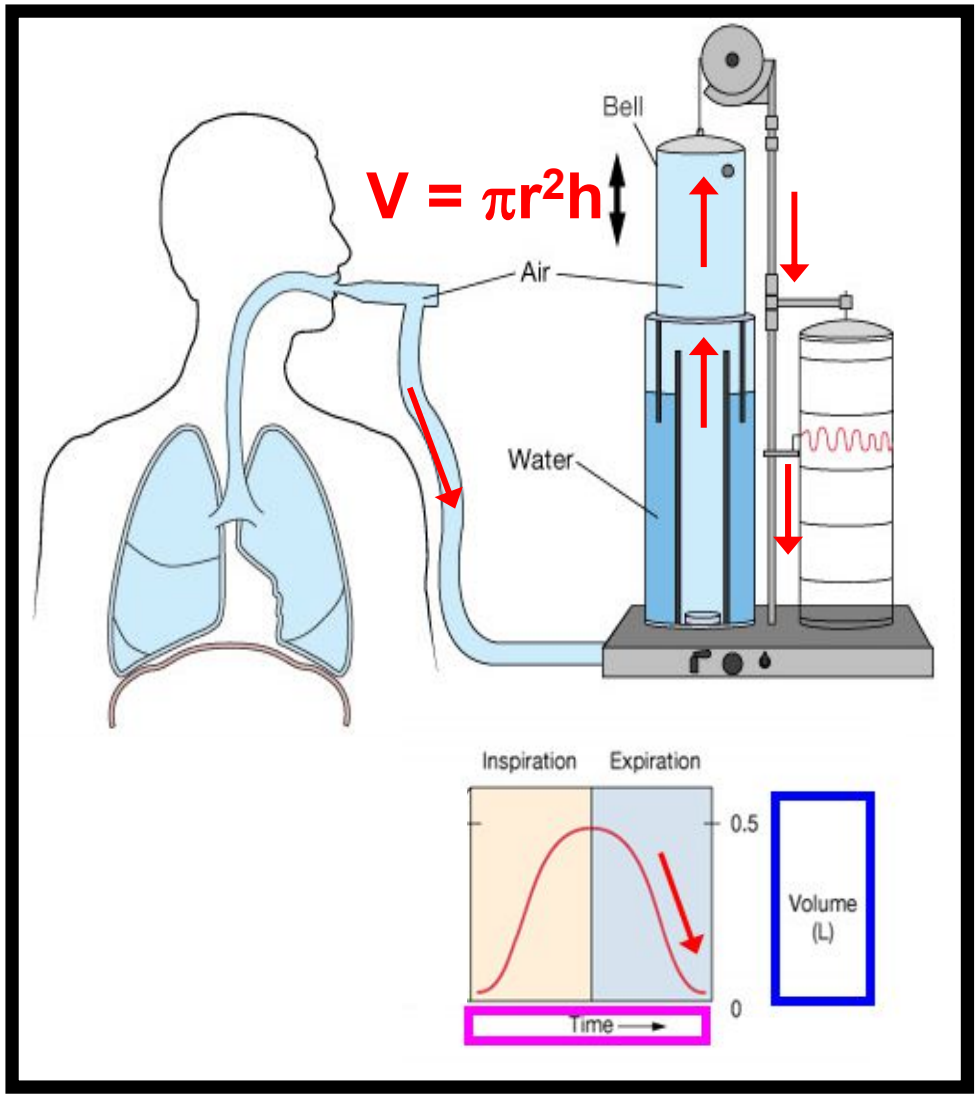
External & Internal Intercostal Muscles

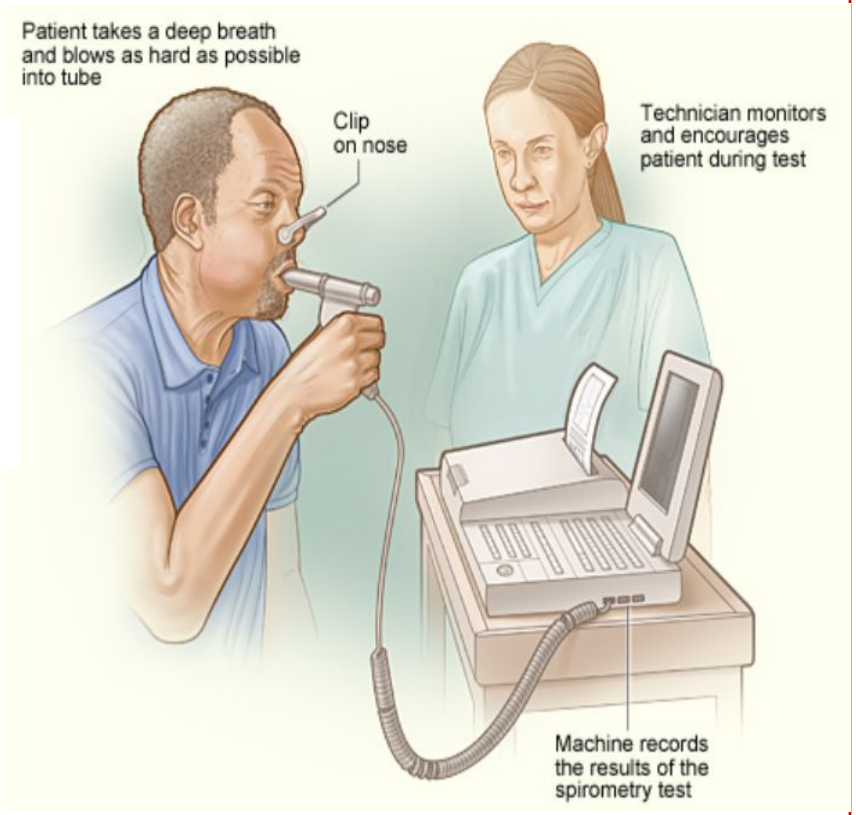


Pulmonary Function Test

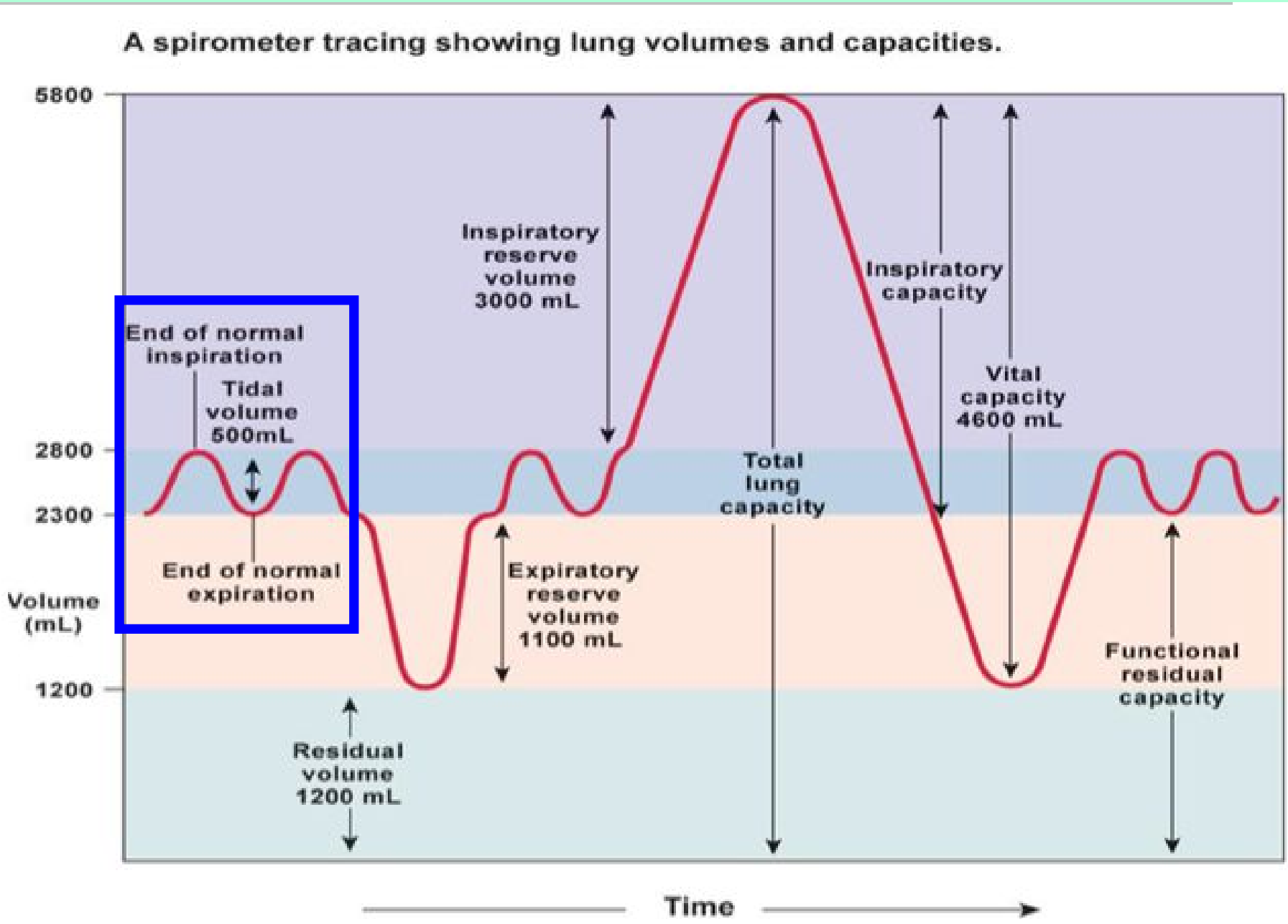
Spirometer:

To measure the volume & rate of air inspired & expired by the lungs





Lung Volumes & Capacities

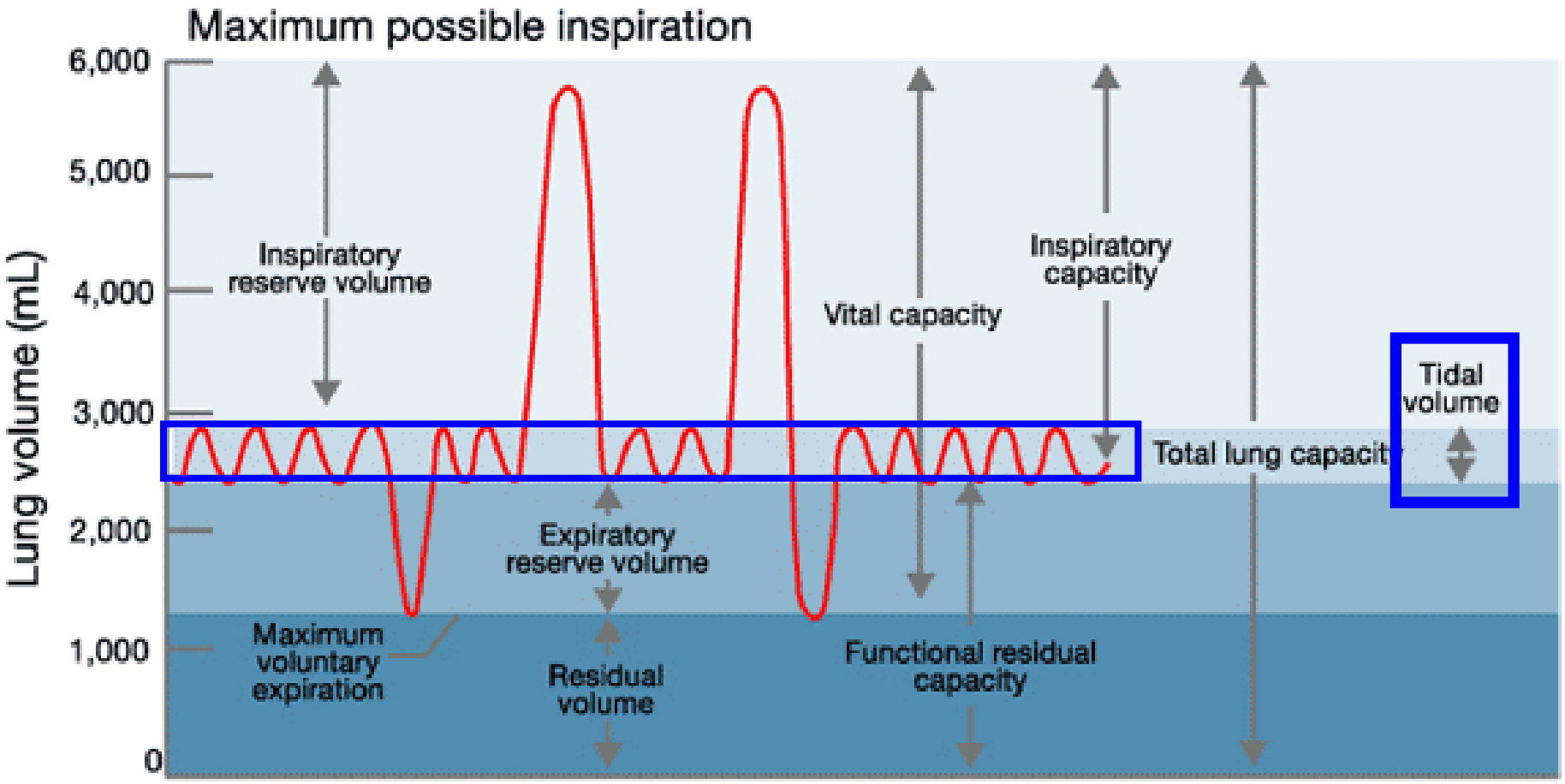


Lung Volumes

- Tidal volume (TV)
- Inspiratory reserve volume (IRV)
- Expiratory reserve volume (ERV)
- Residual volume (RV)

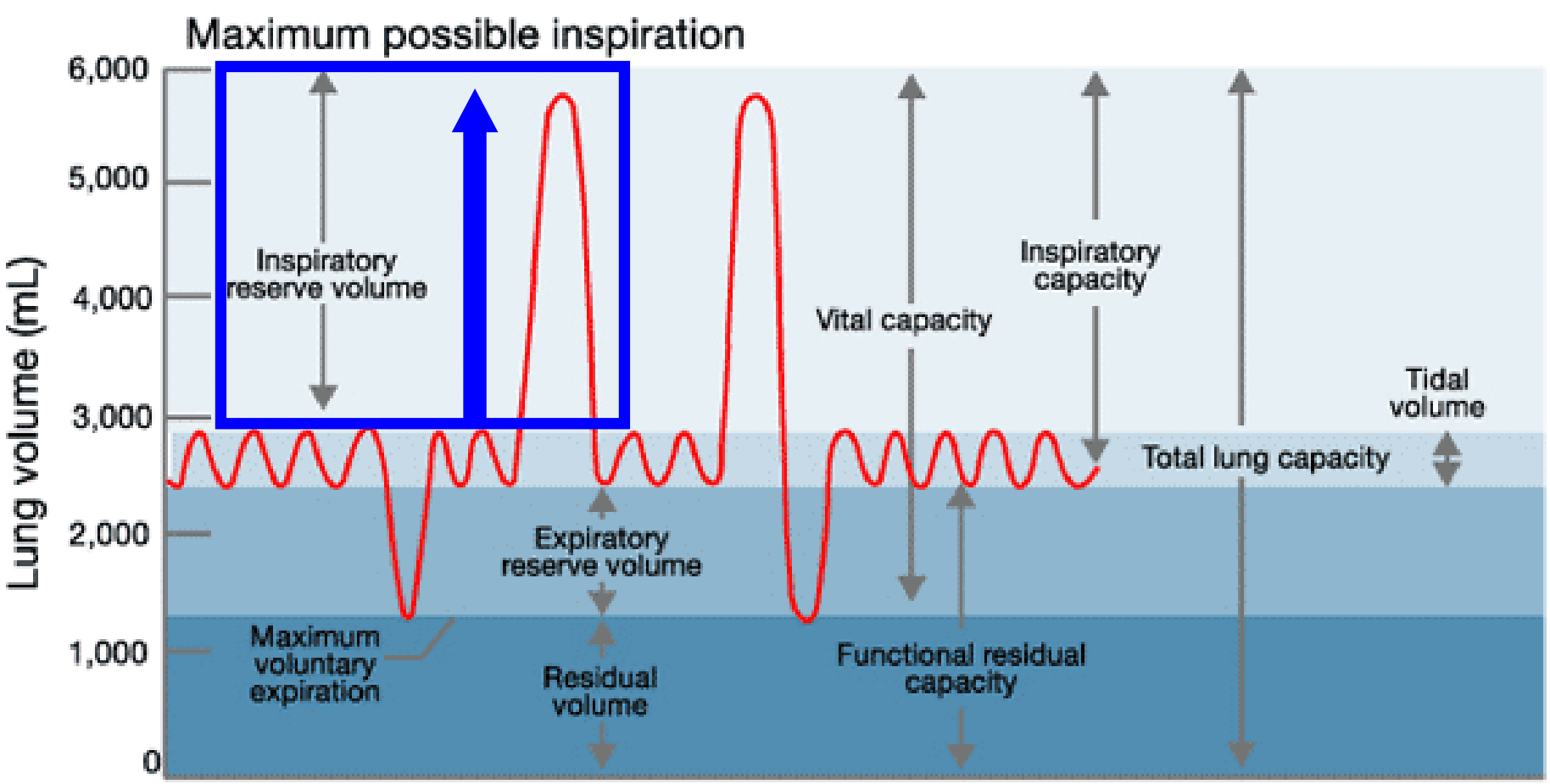
Lung Volumes

- **Tidal volume (TV)** – volume of air that moves into or out of lungs with each normal, quiet breath (~ **500 mL**)



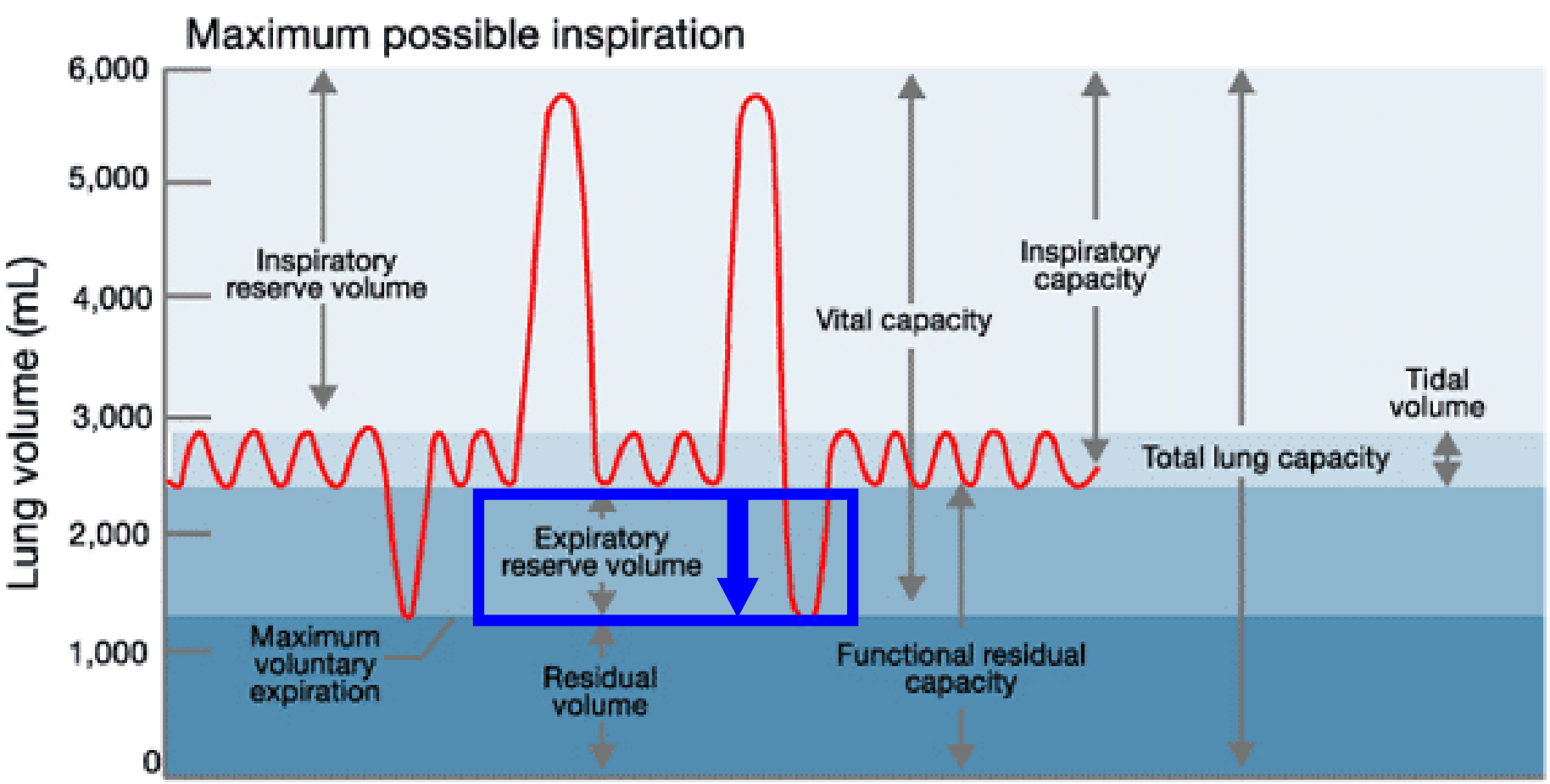
Lung Volumes

- **Inspiratory reserve volume (IRV)** – extra volume of air that can be inspired forcibly (with maximum effort) after a tidal inspiration (2,100 – 3,200 mL)



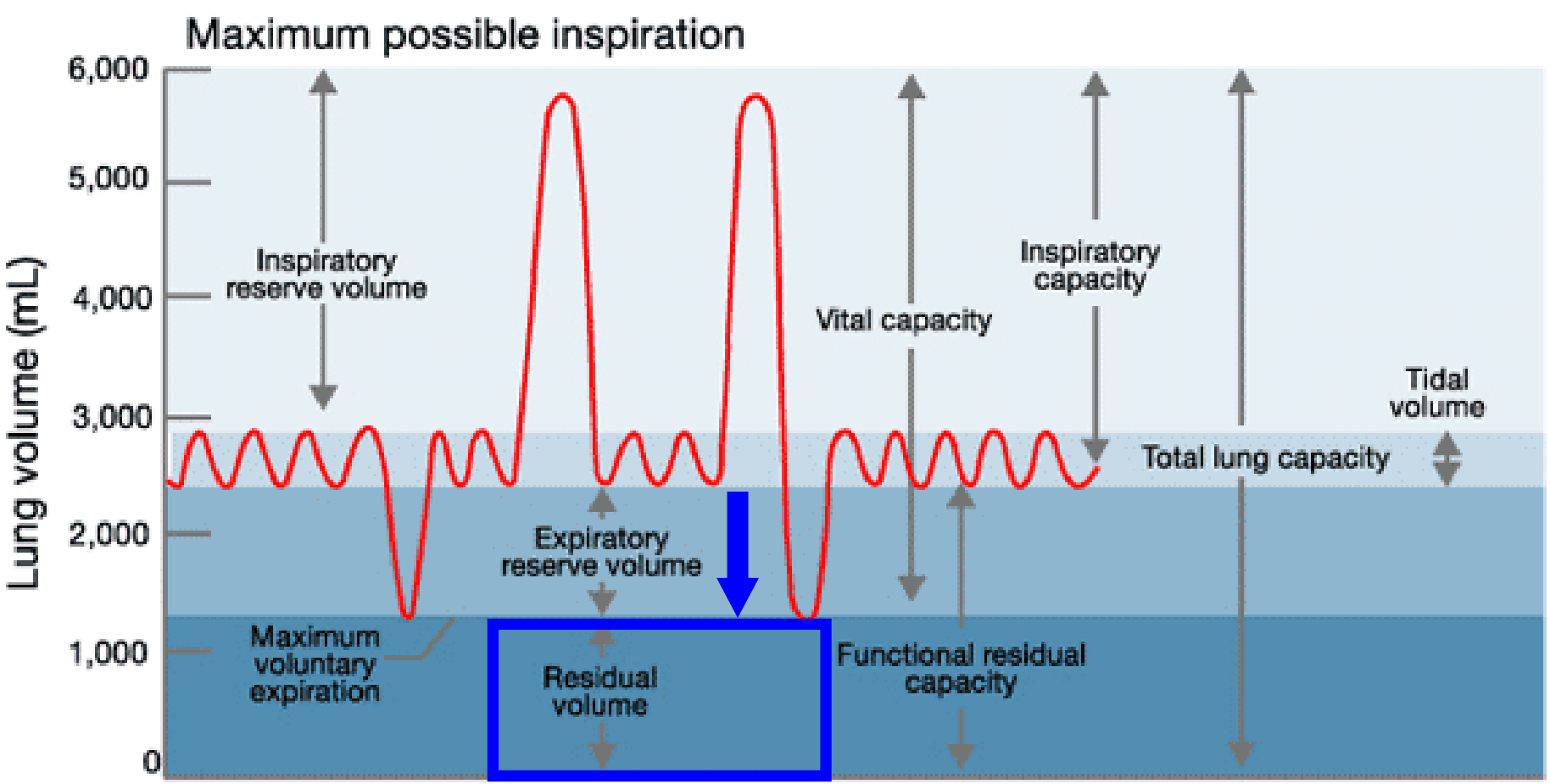
Lung Volumes

- **Expiratory reserve volume (ERV)** – extra volume of air that can be evacuated (with maximum effort) from lungs after a tidal expiration (1,000 – 1,200 mL)



Lung Volumes

- **Residual volume (RV)** – volume of air left in lungs after strenuous expiration (1,200 mL)

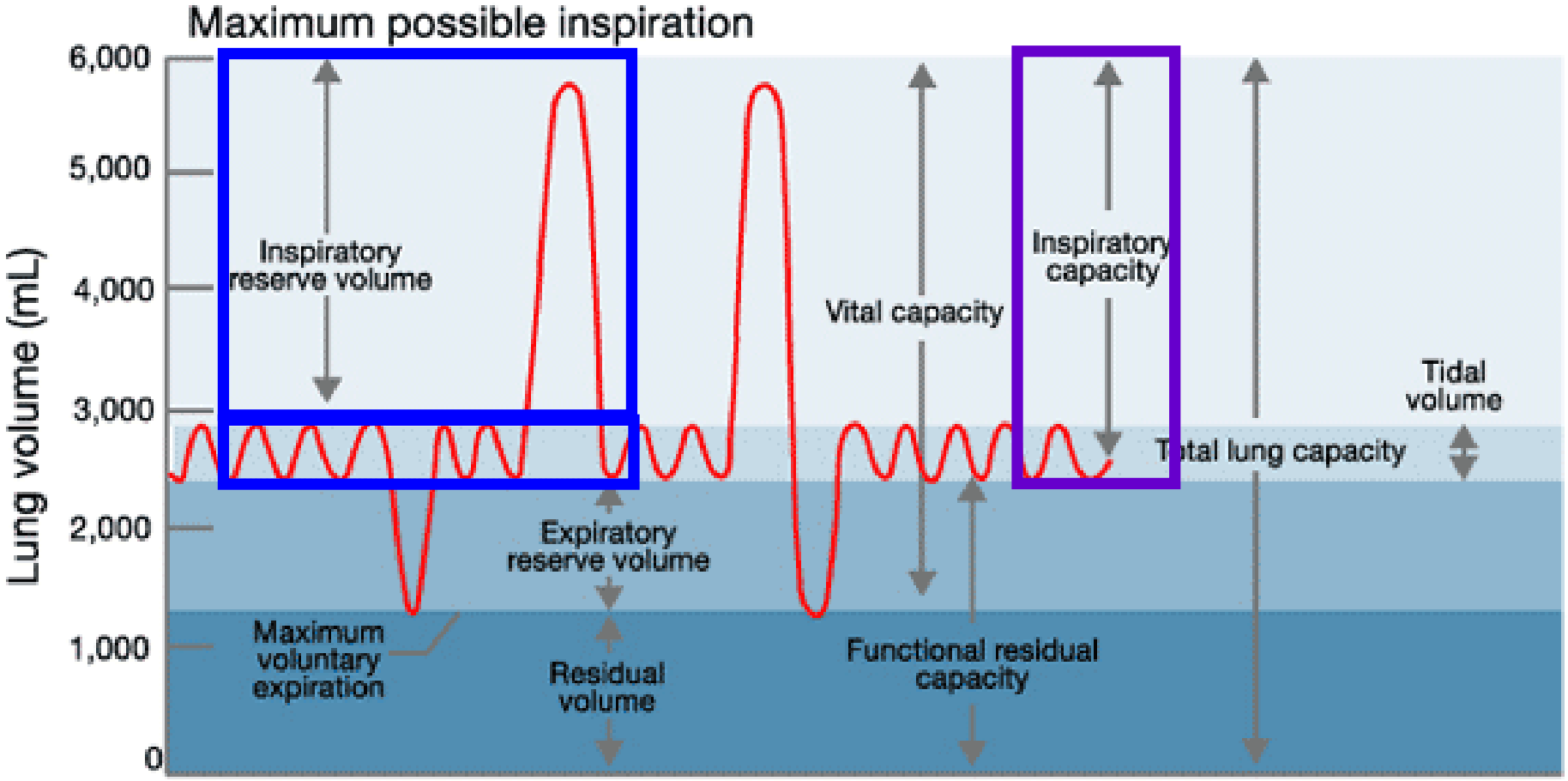


Lung Capacities [sums of 2 or more volumes]

- Inspiratory capacity (IC)
- Functional residual capacity (FRC)
- Vital capacity (VC)
- Total lung capacity (TLC)

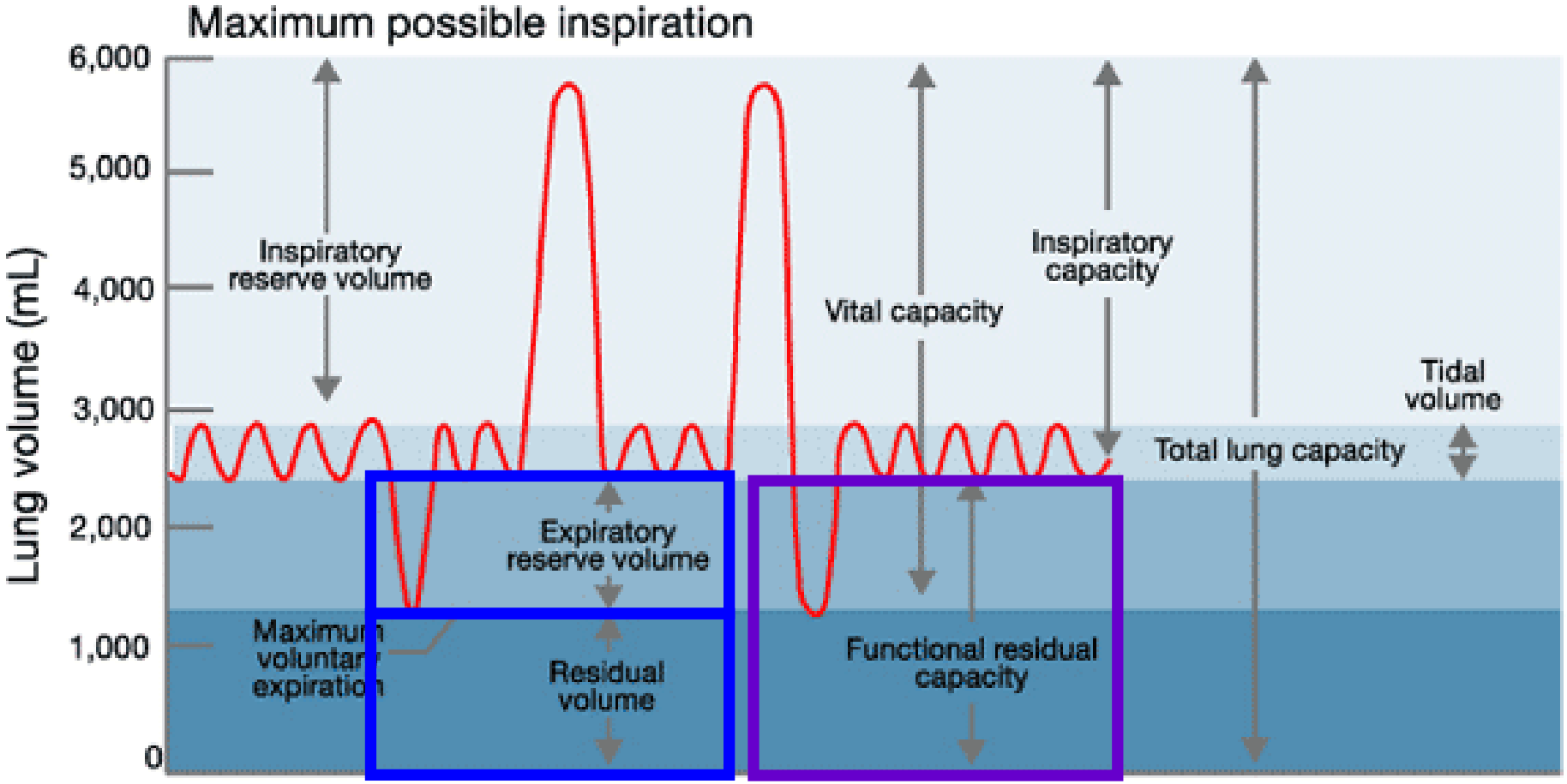
Lung Capacities

- **Inspiratory capacity (IC)** – total amount of air that can be inspired after a tidal expiration (TV + IRV)



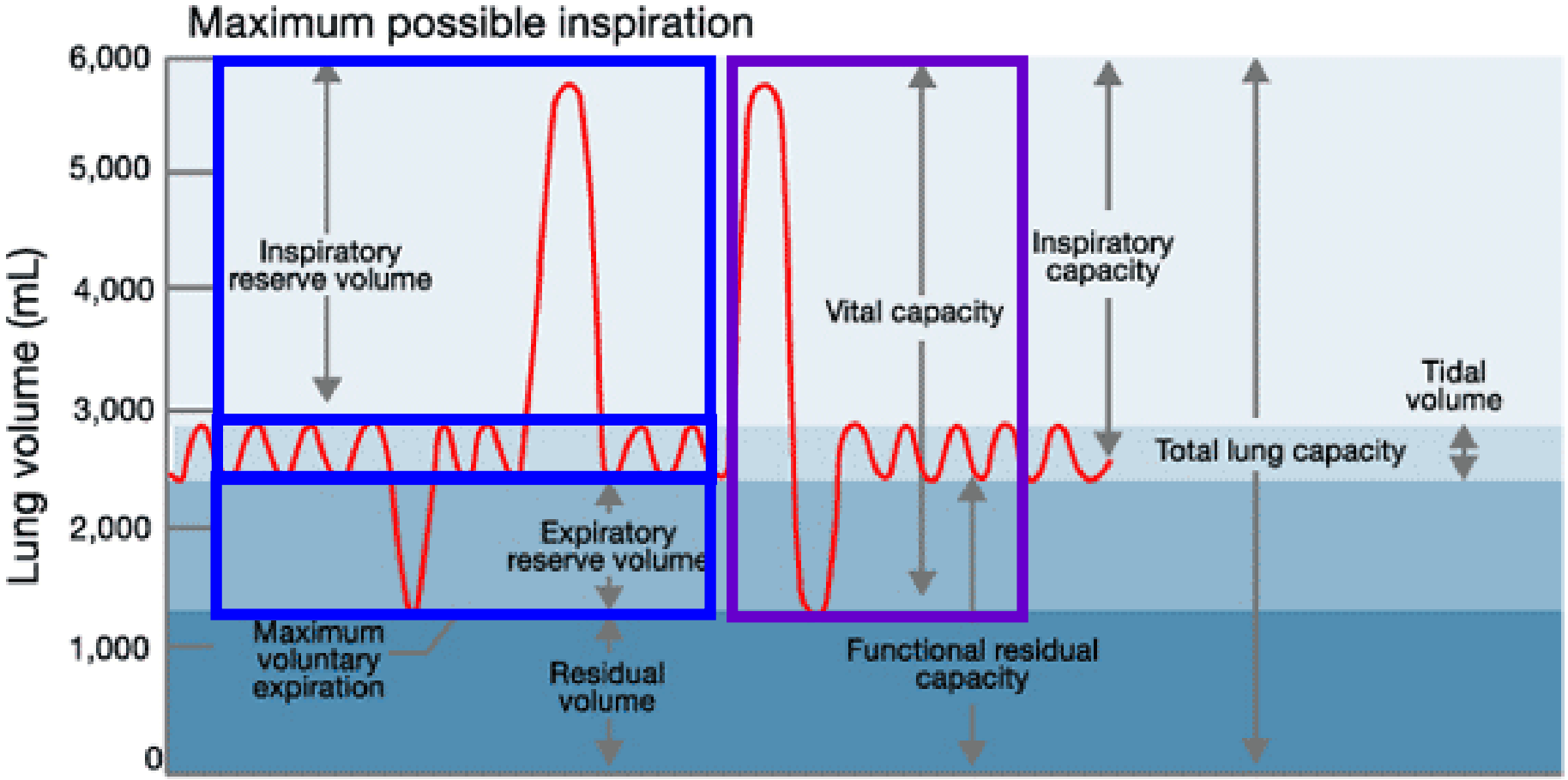
Lung Capacities

- **Functional residual capacity (FRC)** – amount of air remaining in lungs after a tidal expiration (ERV + RV)



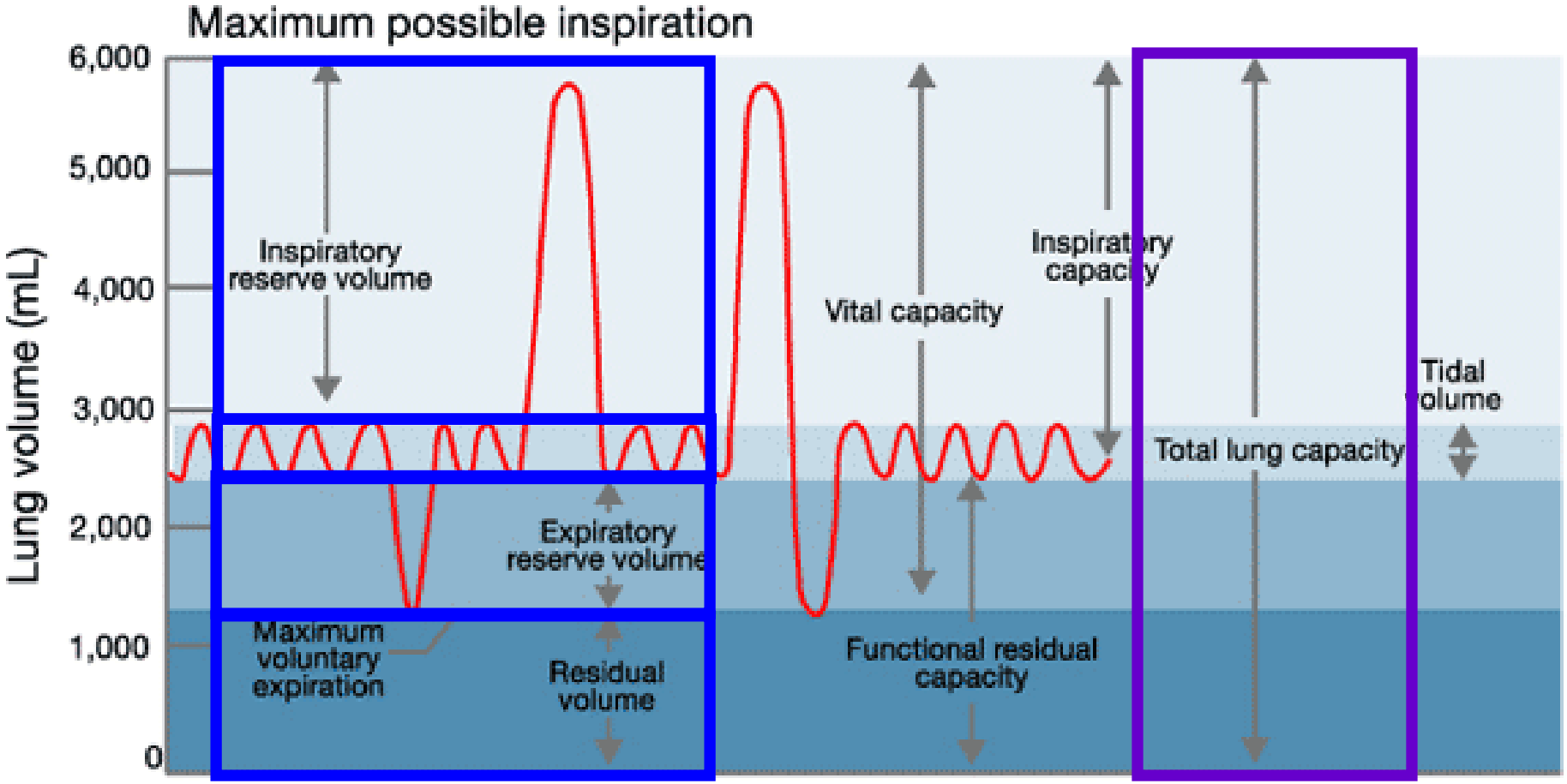
Lung Capacities

- **Vital capacity (VC)** – total amount of exchangeable air (TV + IRV + ERV)

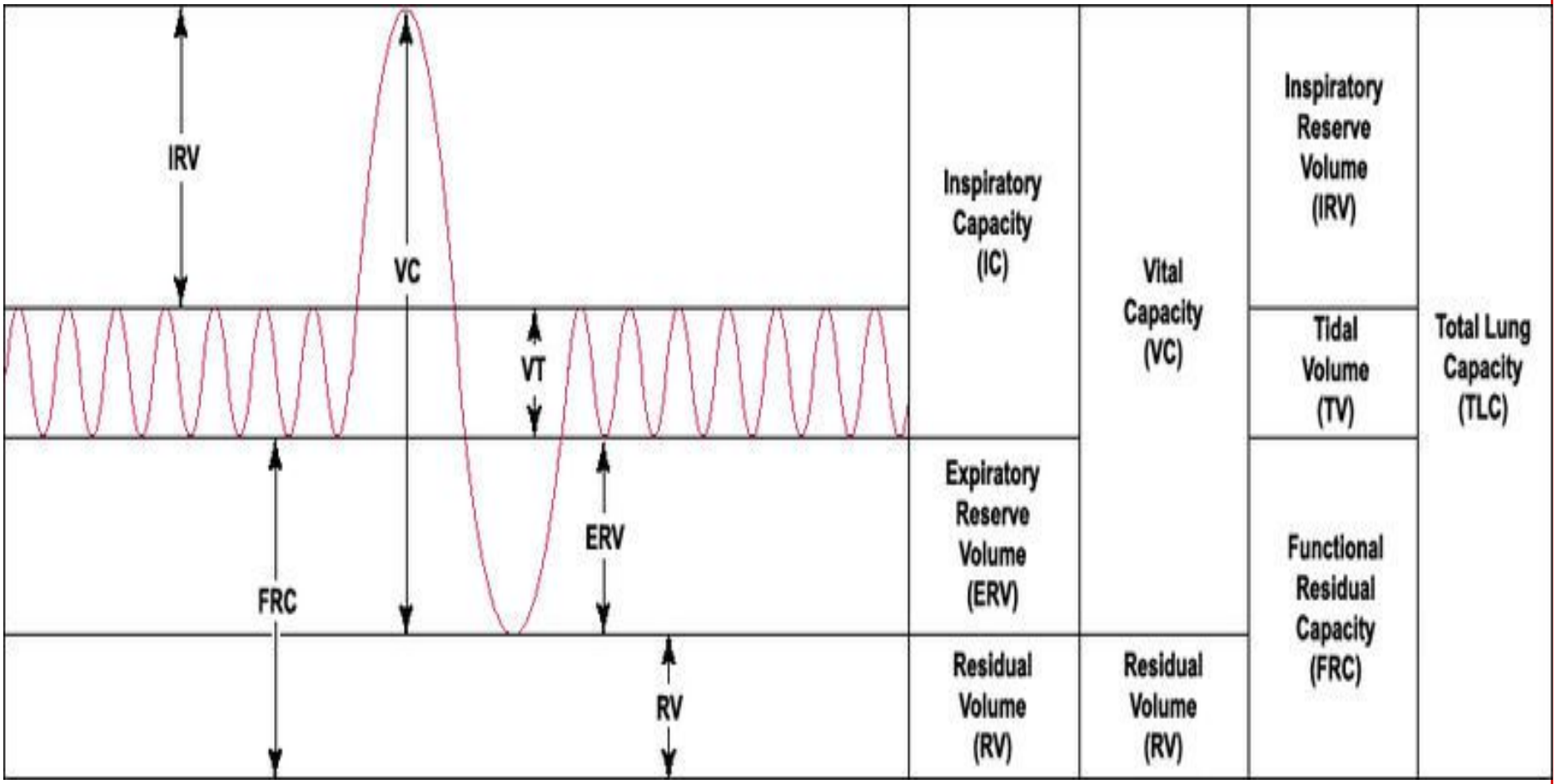


Lung Capacities

- **Total lung capacity (TLC)** – sum of all lung volumes (~ **6,000 mL** in males)



Lung Volume & Capacities



Dead Space

Volume of inhaled air which does not take part in gas exchange

- **Anatomical dead space**:

  Volume of conducting respiratory passageways (150 mL)

- **Alveolar dead space**:

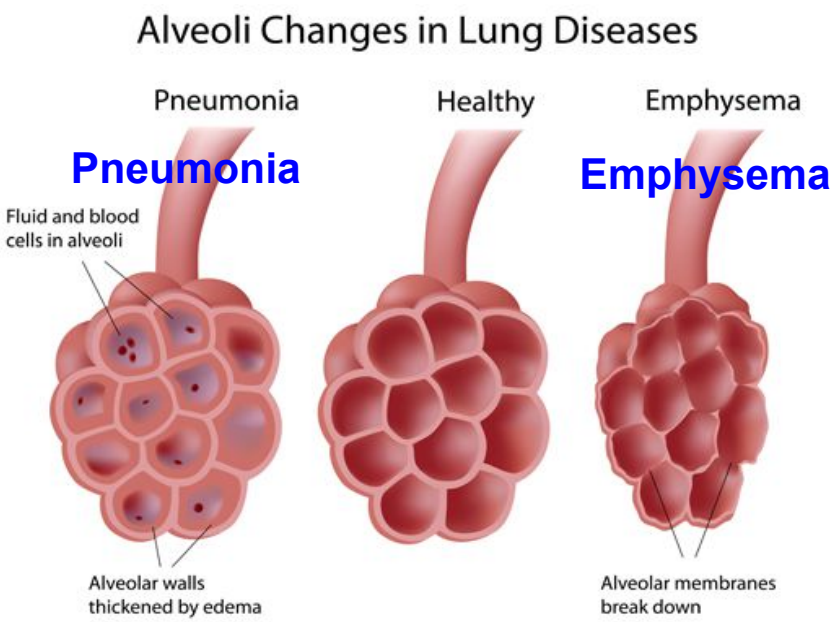
  Volume occupied by alveoli that cease to act in gas exchange (due to collapse, obstruction or lack of adjacent pulmonary capillaries)

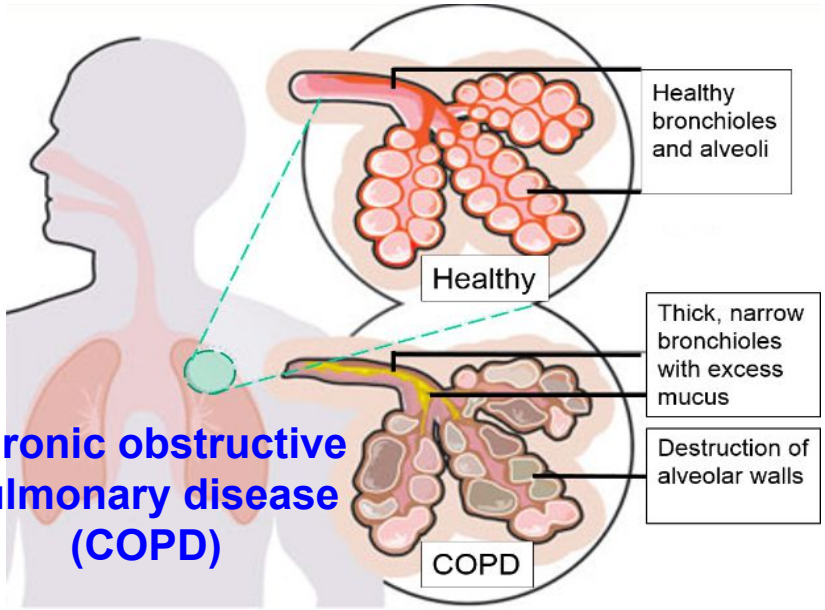
- **Total dead space**

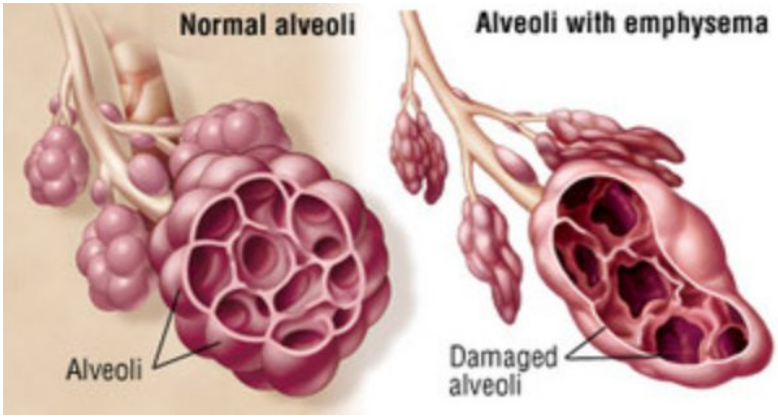
  = Anatomical + Alveolar dead spaces

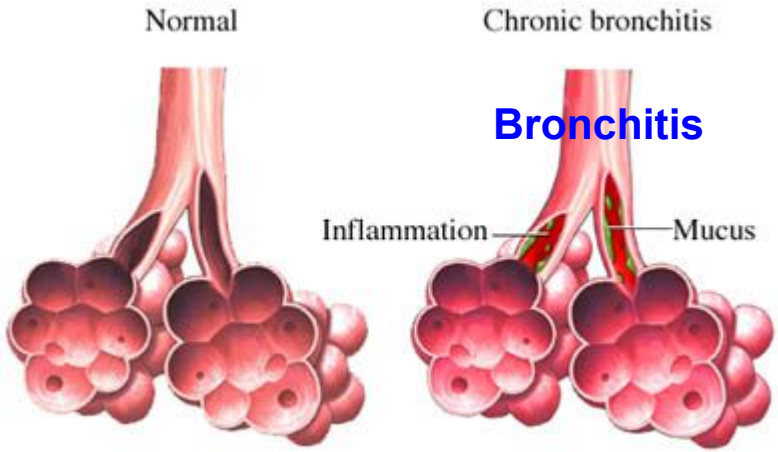
Dead Space

- **Healthy lungs: small alveolar dead space**
- **Certain lung diseases: increase in alveolar dead space**









Non-respiratory Air Movements

Most result from reflex actions

Coughing **Sneezing** **Crying** **Laughing** **Yawning**

Composition of Alveolar Gas

- Atmosphere contains mostly oxygen & nitrogen
- Alveoli contain more carbon dioxide & water vapor
  - Gas exchanges in lungs
    - O_2 diffuses away from alveoli & CO_2 diffuses into alveoli
  - Air is humidified by conducting pathways

Key Points

Inspiration

Diaphragm & external intercostal muscles contract

→ Intrapulmonary volume increases

→ Intrapulmonary pressure drops

→ Air flows into lungs

Expiration

Inspiratory muscles relax

→ Intrapulmonary volumes decreases

→ Intrapulmonary pressure rises

→ Gases flow out of lungs

Forced Inhalation & Expiration

Lung Volumes & Capacities

Dead Space

- Anatomical dead space
- Alveolar dead space

Non-respiratory Air Movements