UNIT 4

Content

- Respiratory System Anatomy
- Pulmonary Ventilation
- Lung Volume and Capacities
- Exchange and Transport of O2 and Co2
- Control of Respiration

Respiratory system

- It is an organ system that rhythmically takes in air and expels it from the body.
- Other functions are:

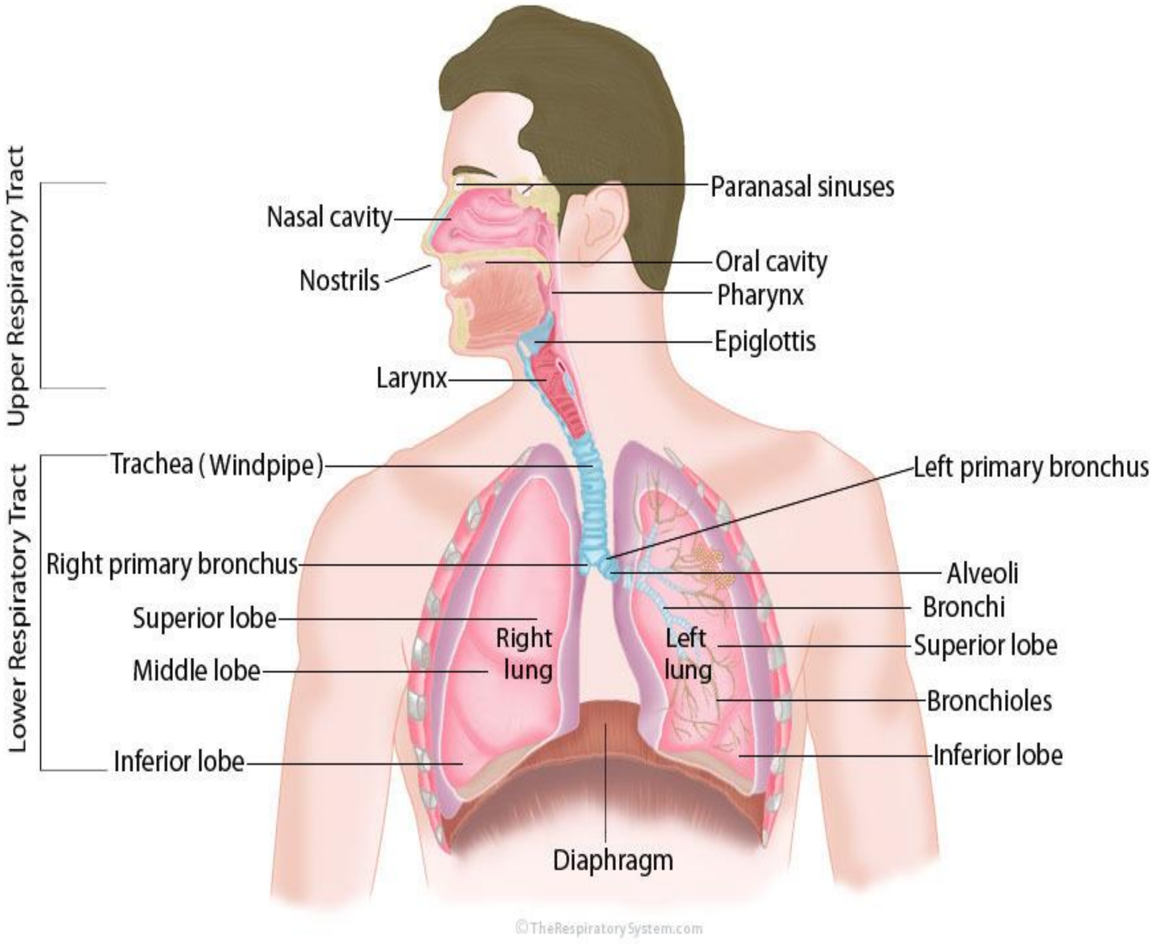
1. Gas exchange
2. Communication
3. Olfaction
4. Acid-base balance
5. Blood pressure regulation- angiotensinogen-II
6. Blood and lymph flow- pressure gradient between thorax and abdomen promote the flow of lymph and venous blood
7. Blood filtration- lungs filter small blood clots from bloodstream and dissolve them
8. Expulsion of abdominal content- breath holding and abdominal contraction
9. Defense mechanism – lungs' own Defense mechanism (defensins and Cathelicidins- antimicrobial), leukocytes(neutrophils & lymphocytes), Macrophages (interleukins, tumor necrosis factor and Chemokines), Mast cells(hypersensitivity Reaction), Natural killer cells (virus and cancer)

Anatomy of respiratory system

- Principal organs of respiratory system includes: pharynx, larynx, trachea, bronchi and lungs.
- Within lungs there is dead end pathway of bronchi, bronchioles and alveoli.
- In general lungs is divided into 2 zones: conducting and respiratory zone.

Conducting zone- passage that serves only for airflow – nose to major bronchioles. There wall is too thick for diffusion of O2.

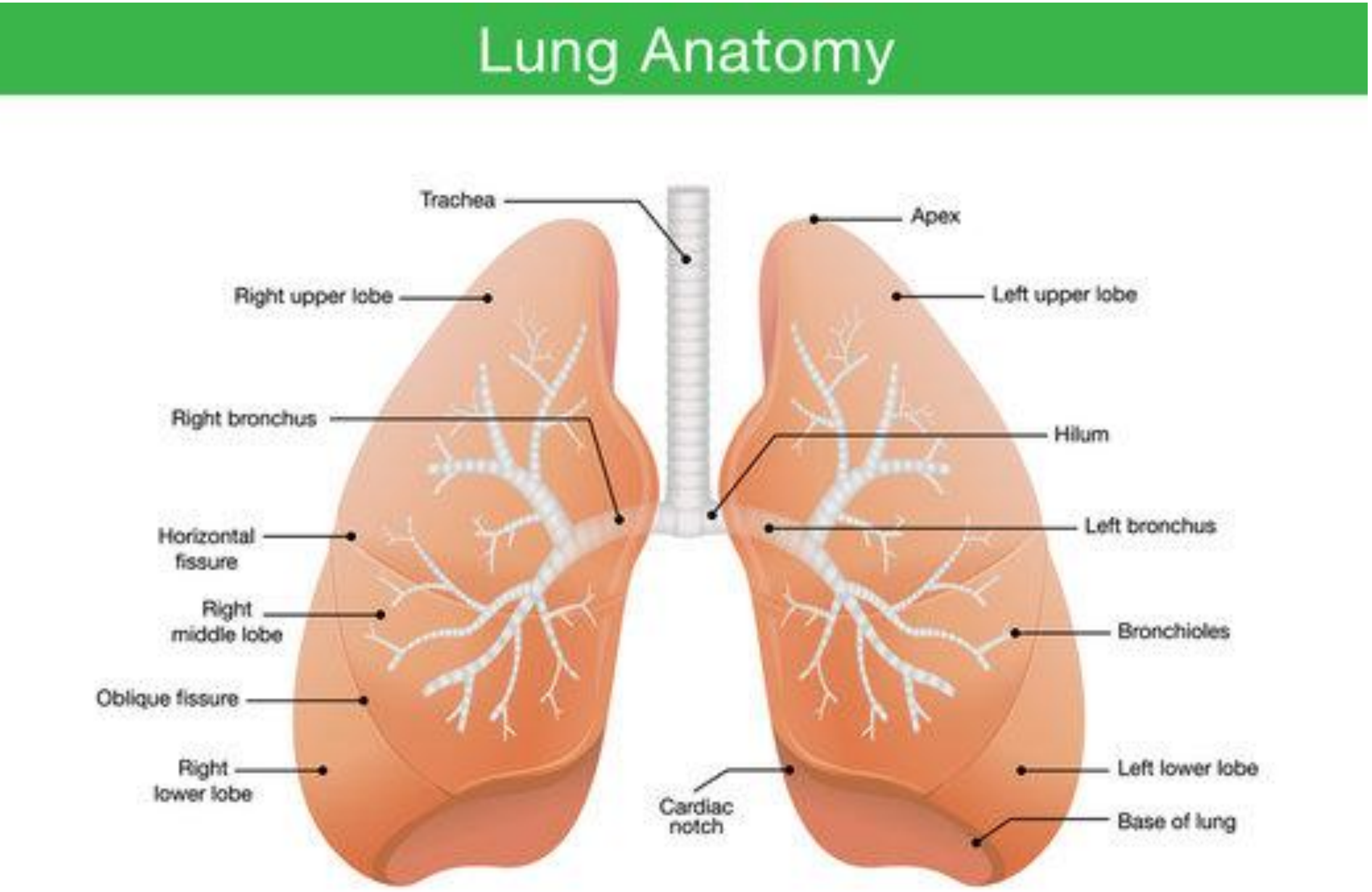
Respiratory zone- alveoli.

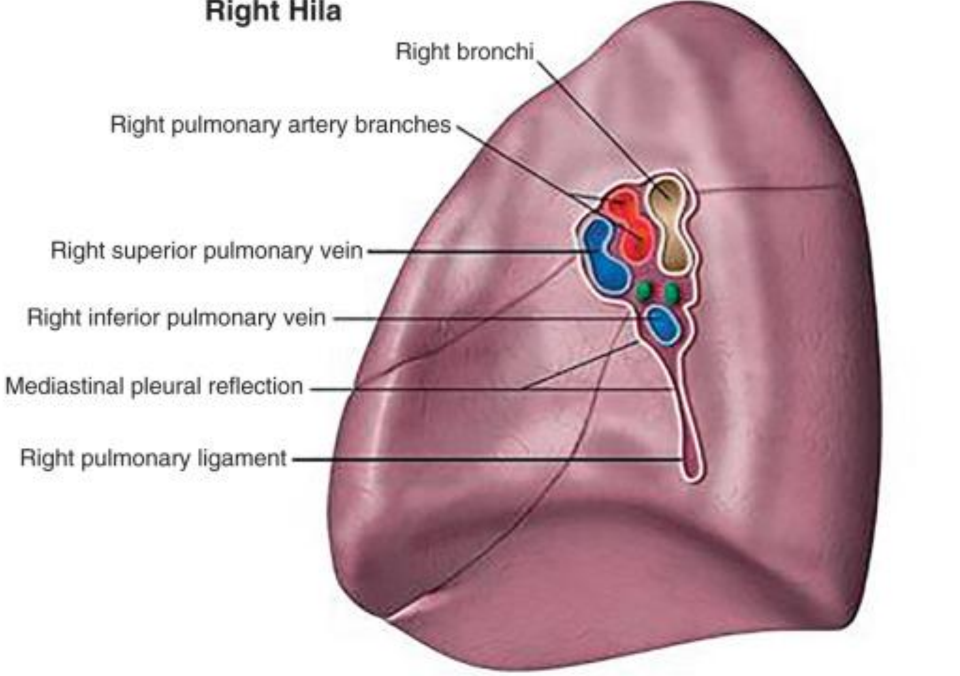


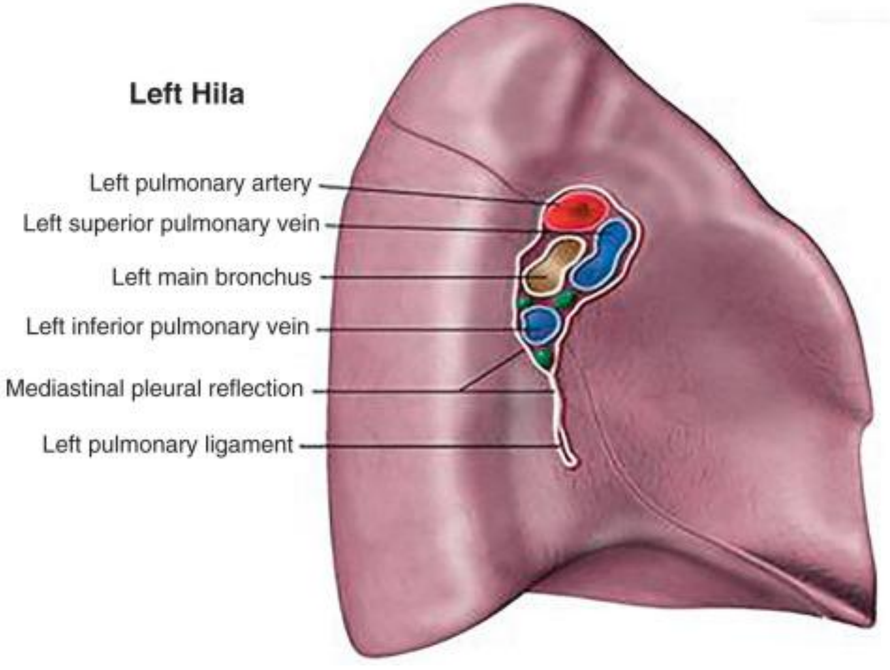
Respiration

- ❖Respiration : O_2/Co_2
- ❖Respiration rate varies with age and between 12-16/minutes in adults.
- ❖External respiration (Ventilation) :exchange of gases in lungs or breathing
- ❖Internal respiration/Cellular respiration : use of oxygen in cellular metabolism [between blood and tissue]
- ❖Phases : expiration and Inspiration
- ❖Eupnea and forced breathing

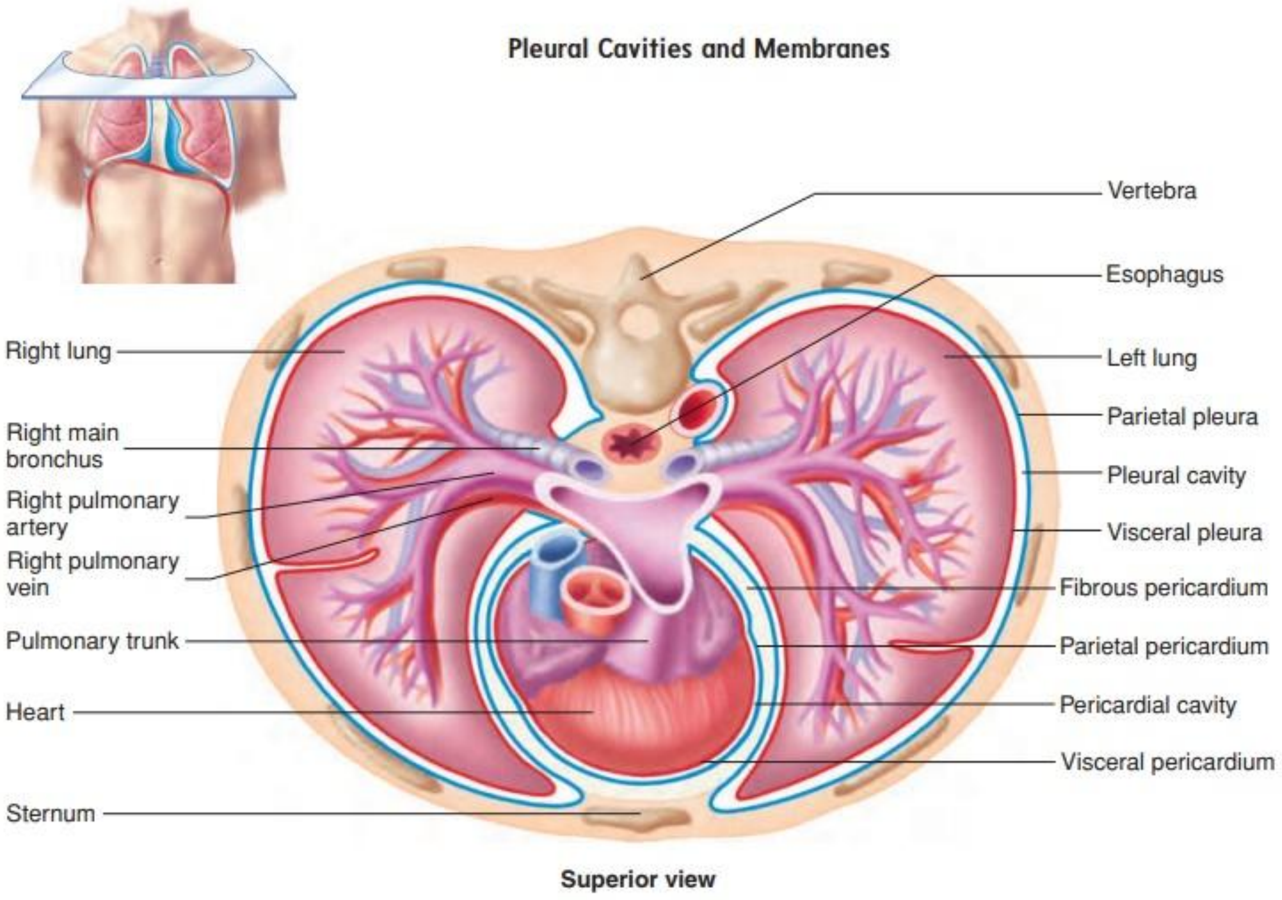
Lungs


Lung Anatomy
Trachea
Apex
Right upper lobe
Left upper lobe
Right bronchus
Hilum
Horizontal fissure
Left bronchus
Right middle lobe
Bronchioles
Oblique fissure
Right lower lobe
Left lower lobe
Cardiac notch
Base of lung


Right Hila
Right bronchi
Right pulmonary artery branches
Right superior pulmonary vein
Right inferior pulmonary vein
Mediastinal pleural reflection
Right pulmonary ligament


Left Hila
Left pulmonary artery
Left superior pulmonary vein
Left main bronchus
Left inferior pulmonary vein
Mediastinal pleural reflection
Left pulmonary ligament

Pleural cavity



Functional anatomy of respiratior

- Pleura :A pleura is a serous membrane that folds back on itself to form a two-layered membranous pleural sac. The outer layer is called the parietal pleura and attaches to the chest wall. The inner layer is called the visceral pleura and covers the lungs, blood vessels, nerves, and bronchi.
- Function of intrapleural space:

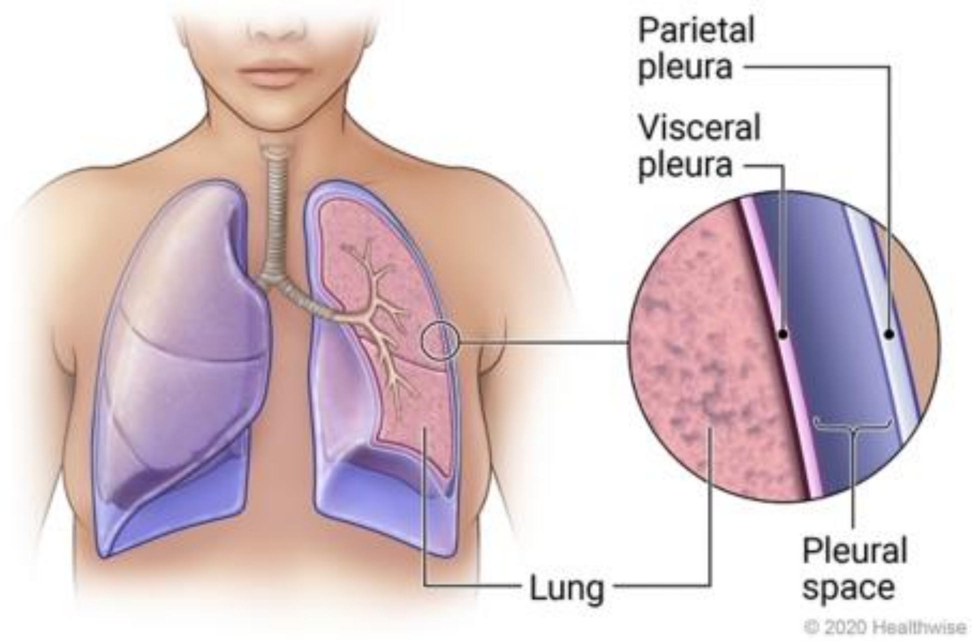
    1. lubricant to prevent friction

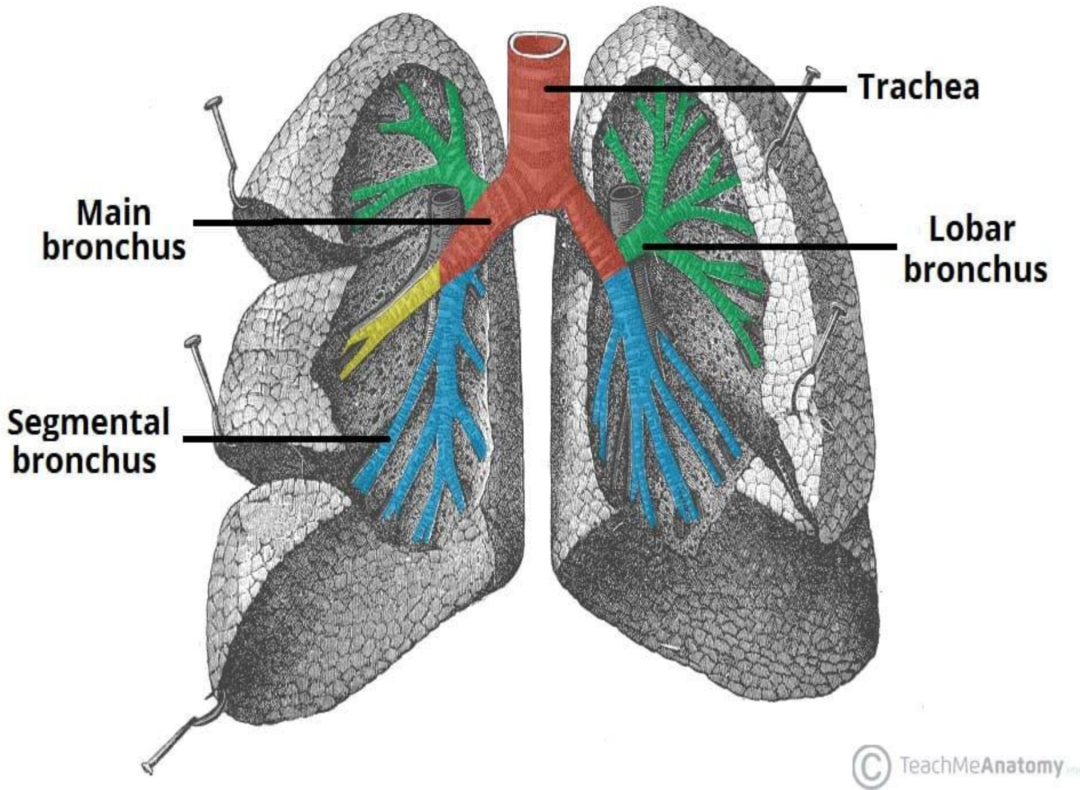
    2. creating negative intrapleural pressure.

    3. pathology pneumothorax (air),hydrothora

    hemothorax and pyothorax(pus).

- Tracheobronchial tree: primary, lobar, segmental c tertiary bronchi-> many generations of bronchioles, terminal bronchioles (dia<1mm), respiratory bronchioles (dia<0.5mm).



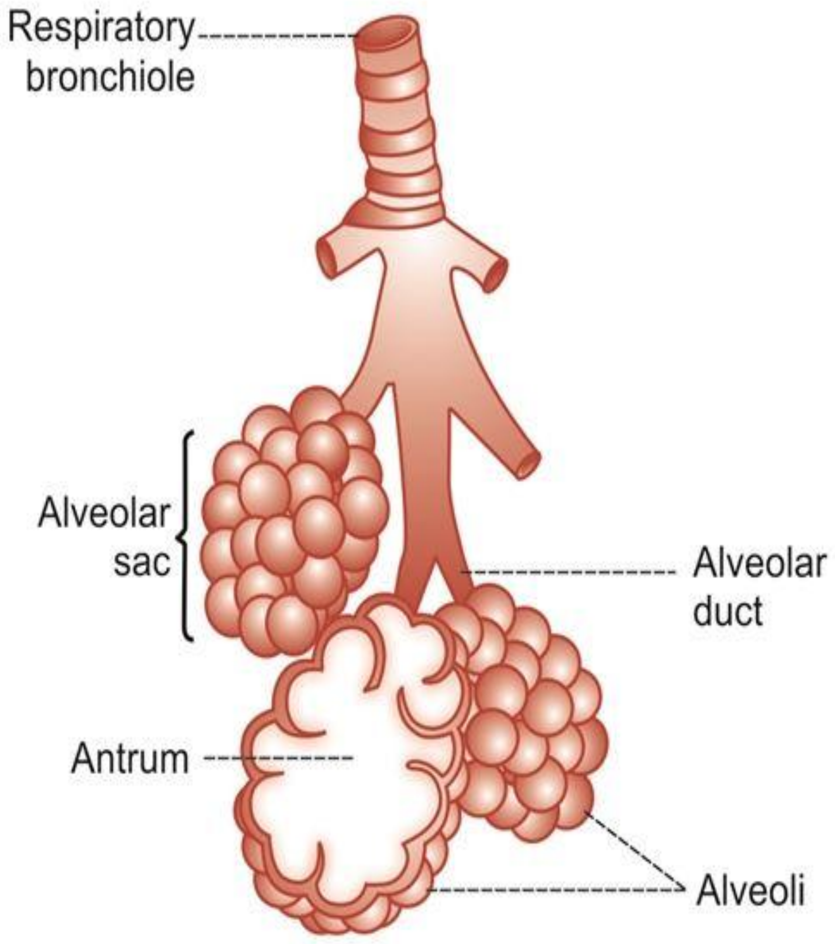


Respiratory units

- Lung parenchyma is formed by respiratory unit that forms the terminal portion of respiratory tract. It includes:

1. Respiratory Bronchioles,2. Alveolar Ducts
3. Antrum, 4. Alveolar Sacs, 5. Alveoli(150 million- $70m^2$area/lung)

- Each alveolus is like a pouch with diameter of about 0.2-0.5mm. It is lined by epithelial cells.
- Alveolar cells or pneumocytes : type I – are squamous epithelial cells forming about 95% of total surface area. Responsible for rapid gaseous exchange.
- Great (Type-II) alveolar cell – cuboidal -> secrete the alveolar fluid and surfactants. They cover less surface area but they are considerably out numbers the squamous alveolar cells. Other function is repair damaged squamous cells.



Respiratory membrane

- Made up of squamous alveolar cell, basement membrane and endothelial cell of capillary. Its total thickness is 0.5µm.
- It is important to prevent fluid from accumulating in the alveoli, because gas diffuses too slowly through liquid. Excess liquid is absorbed by blood capillaries.
- There mean blood pressure is only 10mmHg compared to 30mmHg at arterial end of average capillary.

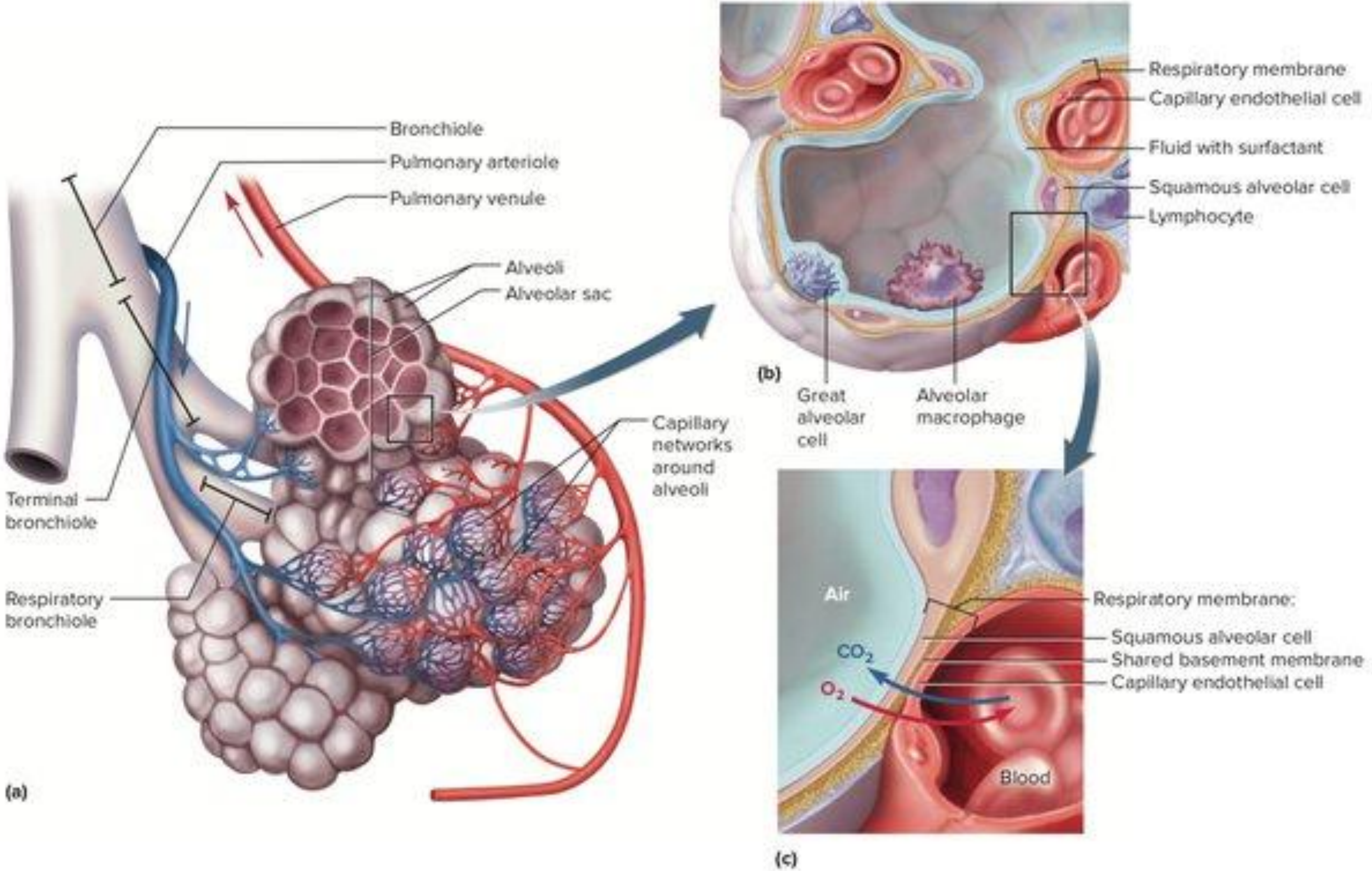
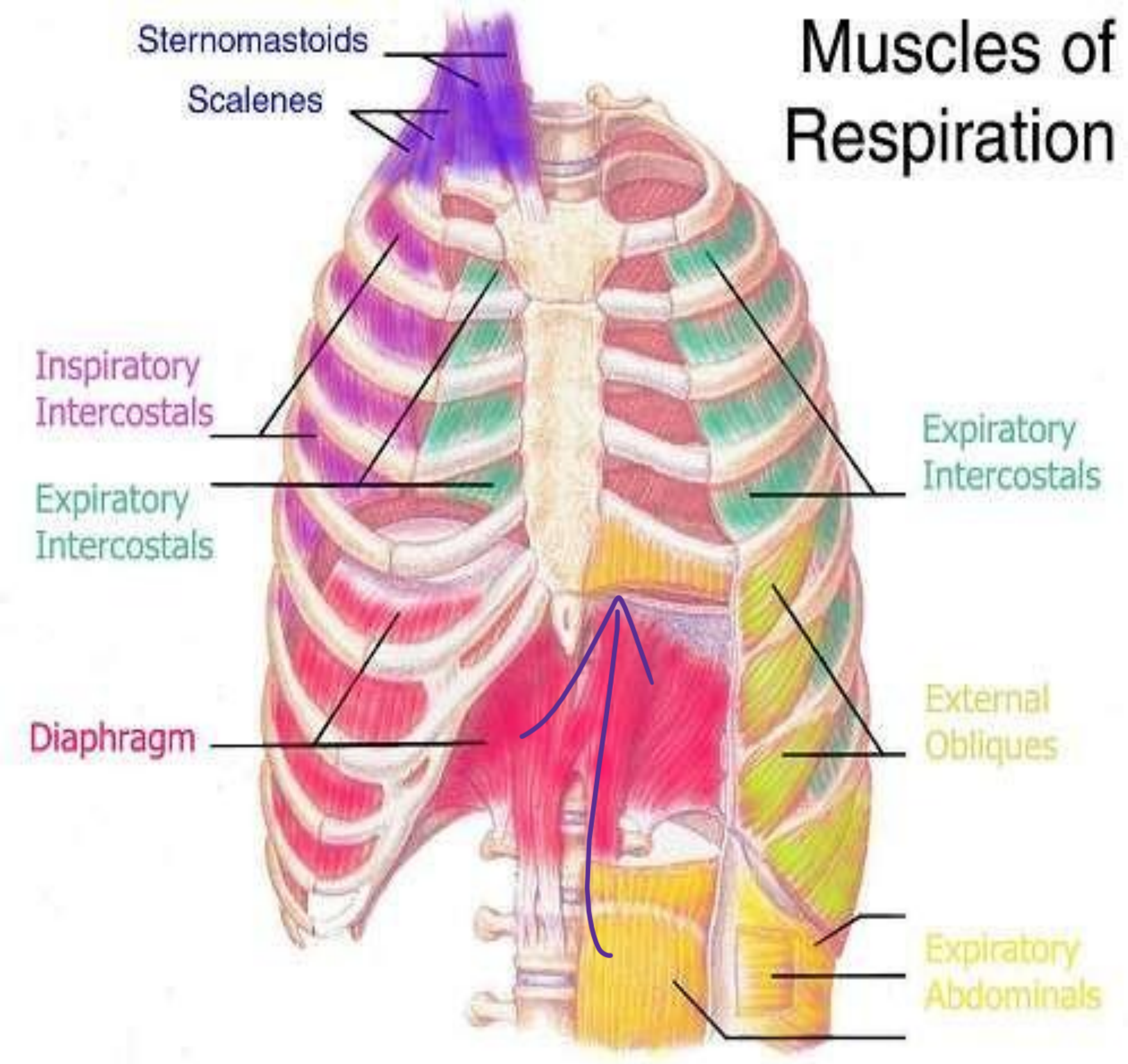


FIGURE 22.12 Pulmonary Alveoli. (a) Clusters of alveoli and their blood supply. (b) Structure of an alveolus. (c) Structure of the respiratory membrane.

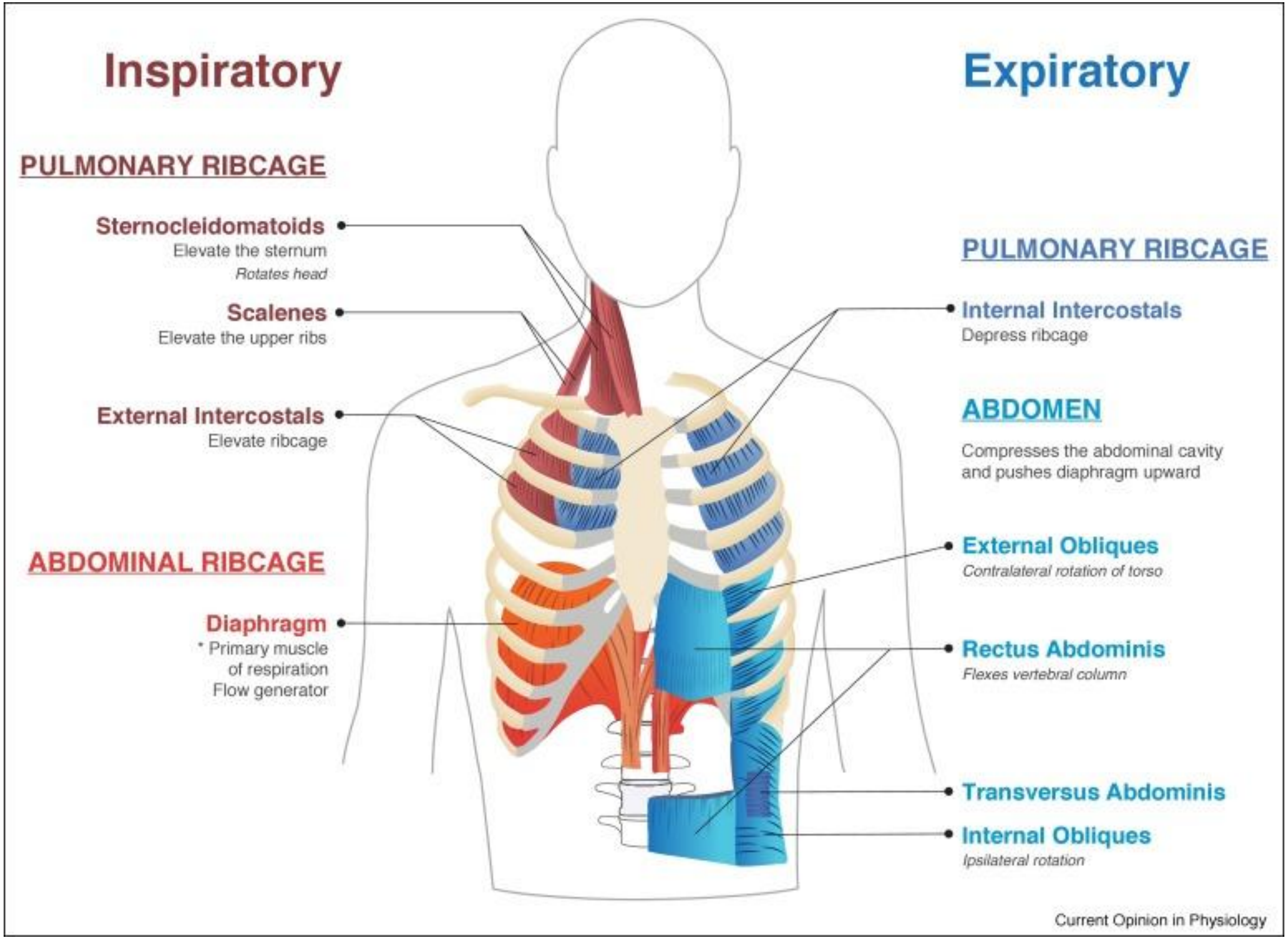
Respiratory mechanism

- Inspiration is an active process, which occurs due to contraction of Inspiratory muscles, whereas normal expiration is a passive phenomenon that occurs due to elastic recoil of the lungs.
- Contraction of Inspiratory muscles expands the thoracic cavity that leads to decreased intrapleural pressure. Drop in intrapleural pressure helps the lungs to expand.
- The expansion of lungs decreases intrapulmonary pressure to sub atmospheric level due to which air from atmosphere is sucked in to the lungs.
- Muscle expand (primary IM)→ decrease Intrapleural P → lungs expansion → intrapulmonary p decrease → air can come inside lun

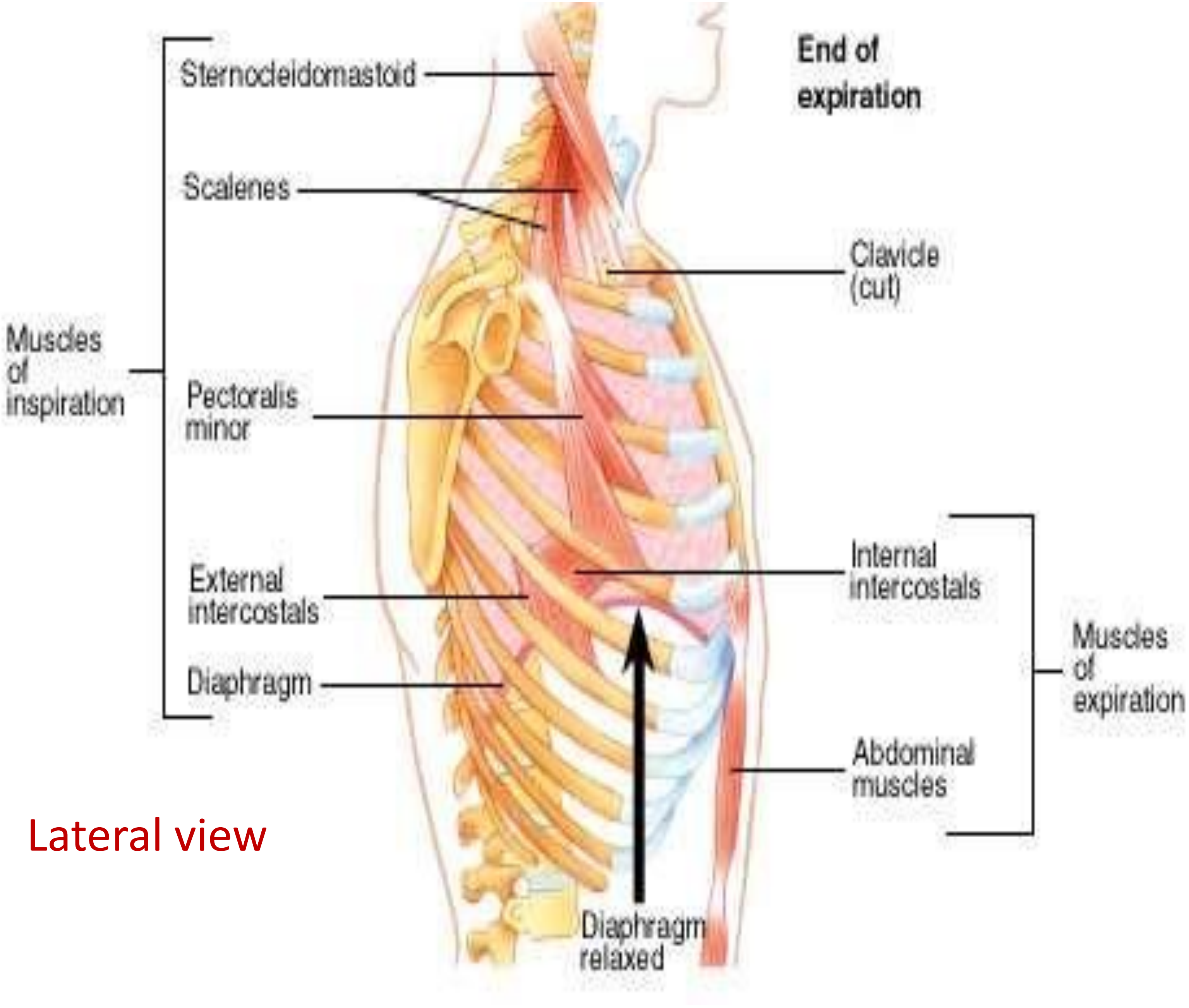
Respiratory muscles



- Main muscles for Inspiration: Diaphragm and External intercostal Muscle.
- Muscles for expiration: Internal intercostal, Pectoral, Abdominal muscles



Inspiratory
Expiratory
PULMONARY RIBCAGE
Sternocleidomatoids
Elevate the sternum
Rotates head
Scalenes
Elevate the upper ribs
External Intercostals
Elevate ribcage
ABDOMINAL RIBCAGE
Diaphragm
* Primary muscle
of respiration
Flow generator
PULMONARY RIBCAGE
Internal Intercostals
Depress ribcage
ABDOMEN
Compresses the abdominal cavity
and pushes diaphragm upward
External Obliques
Contralateral rotation of torso
Rectus Abdominis
Flexes vertebral column
Transversus Abdominis
Internal Obliques
Ipsilateral rotation
Current Opinion in Physiology



Lateral view

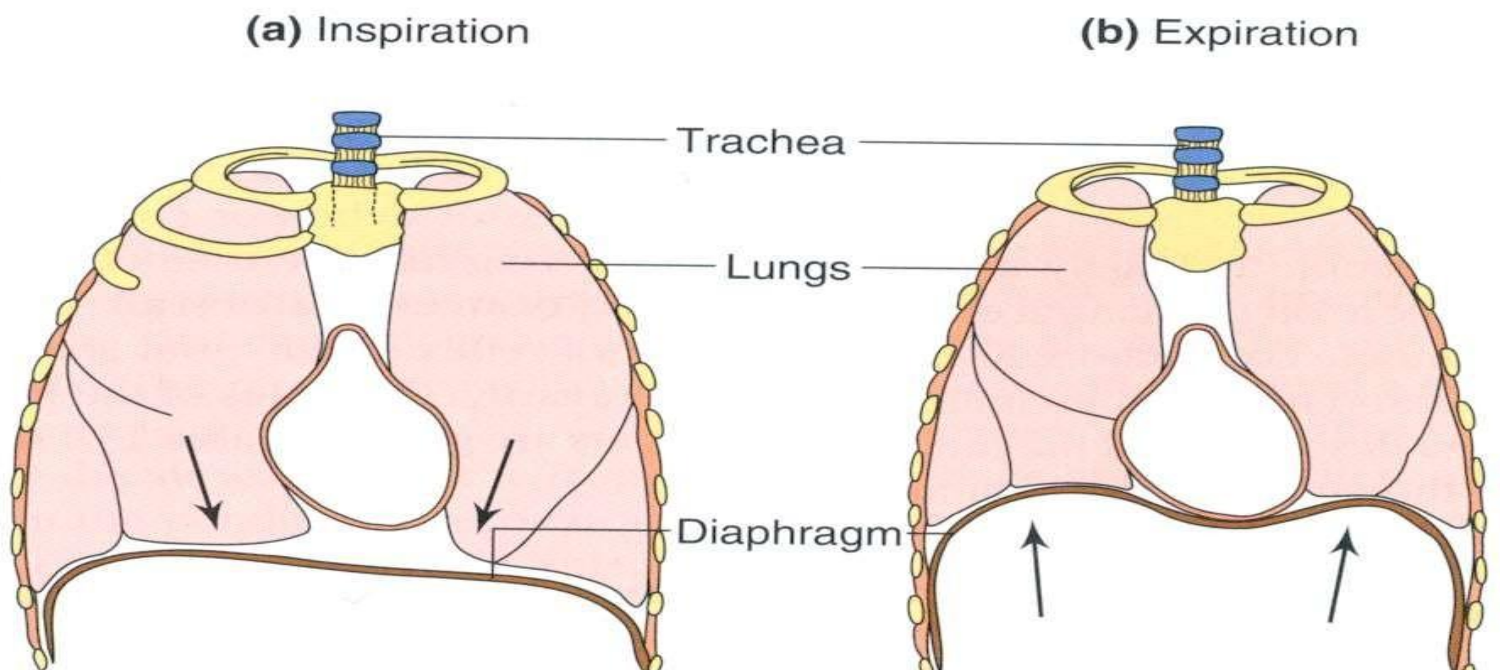
- Accessory muscles of Inspiration

i. Accessory Inspiratory: Sternomastoid, Scal
Anterior Serrati, Elevators of Scapula & Pec

- Accessory muscles of Expiration
- Abdominal muscles
- The internal intercostals
- Neck and back muscles

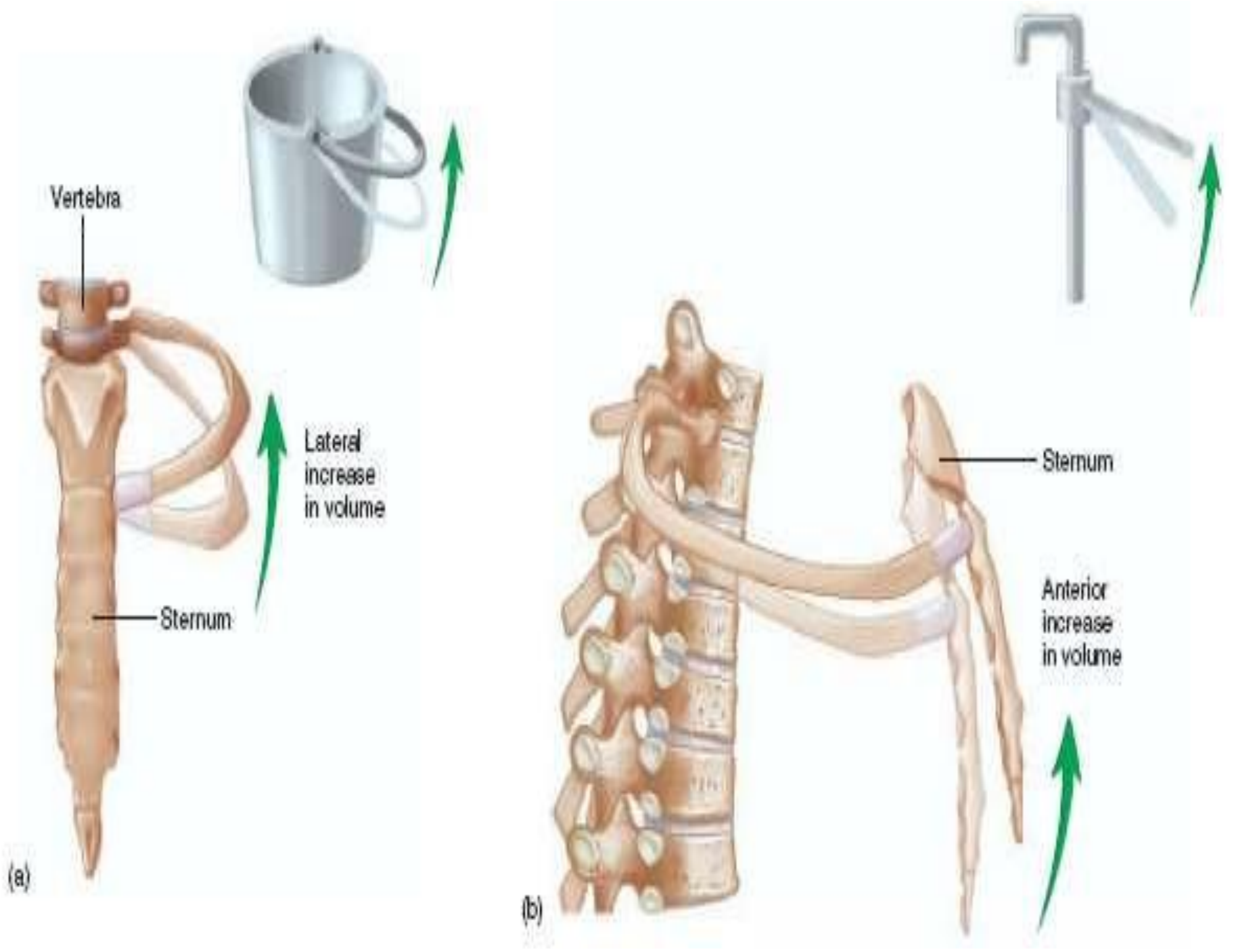
Diaphragm

- The diaphragm is the main muscle of inspiration, which is a skeletal muscle. Inflation of the lungs is caused primarily by contraction of diaphragm.
- Contraction of diaphragm expands thoracic cavity into two ways:
- The diaphragm is dome shaped and attached to the lower six ribs and the xiphoid process of the sternum. Thus, when it contracts, the dome is flattened and abdominal contents are pushed downward so that the thoracic cavity enlarges in its rostrocaudant extent. Thus, the vertical diameter of thoracic cage increases
- Contraction of diaphragm also pushes the rib cage outward that enlarges the thoracic cavity in its antero- posterior and lateral planes.

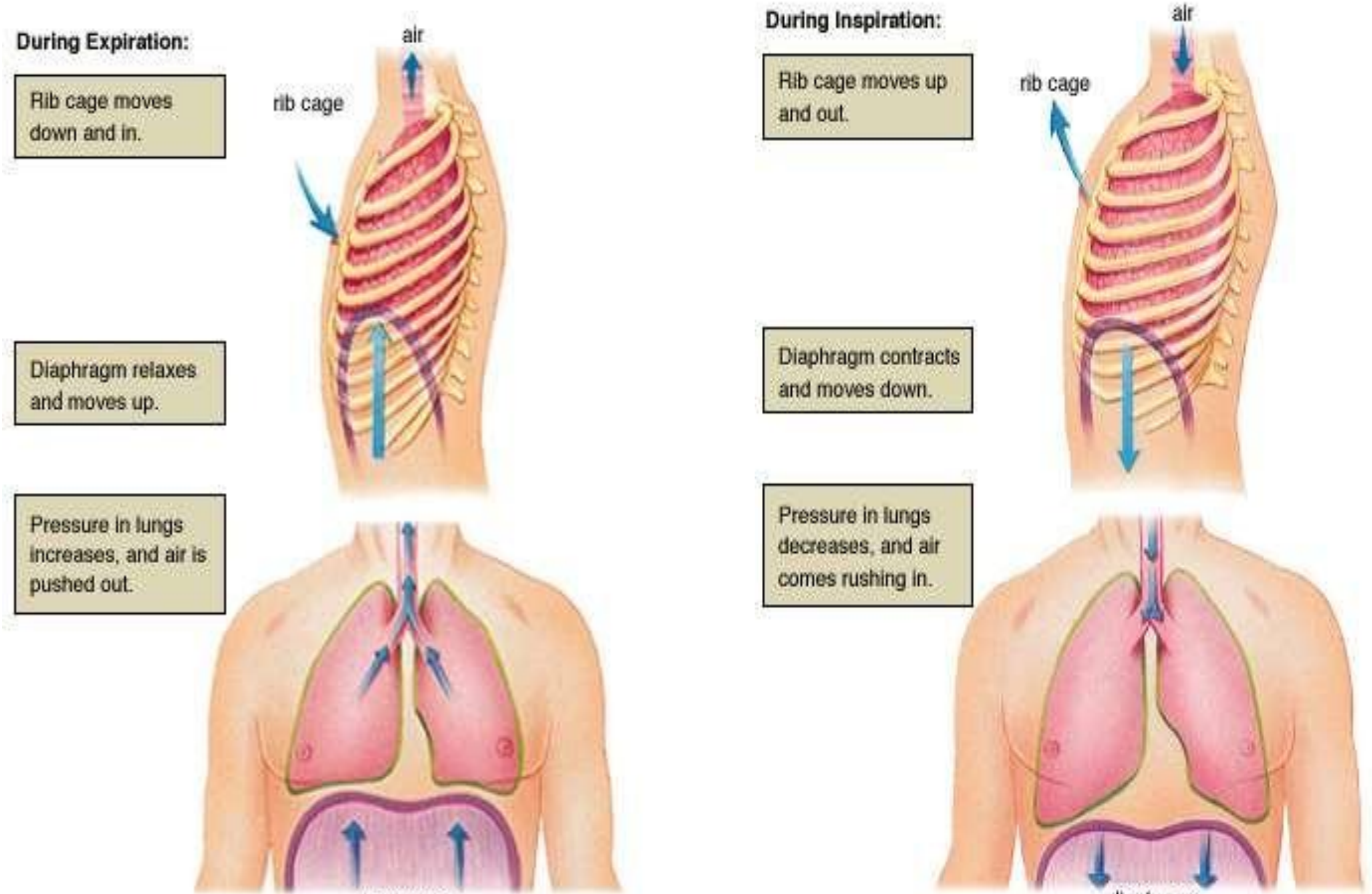


External intercoastal

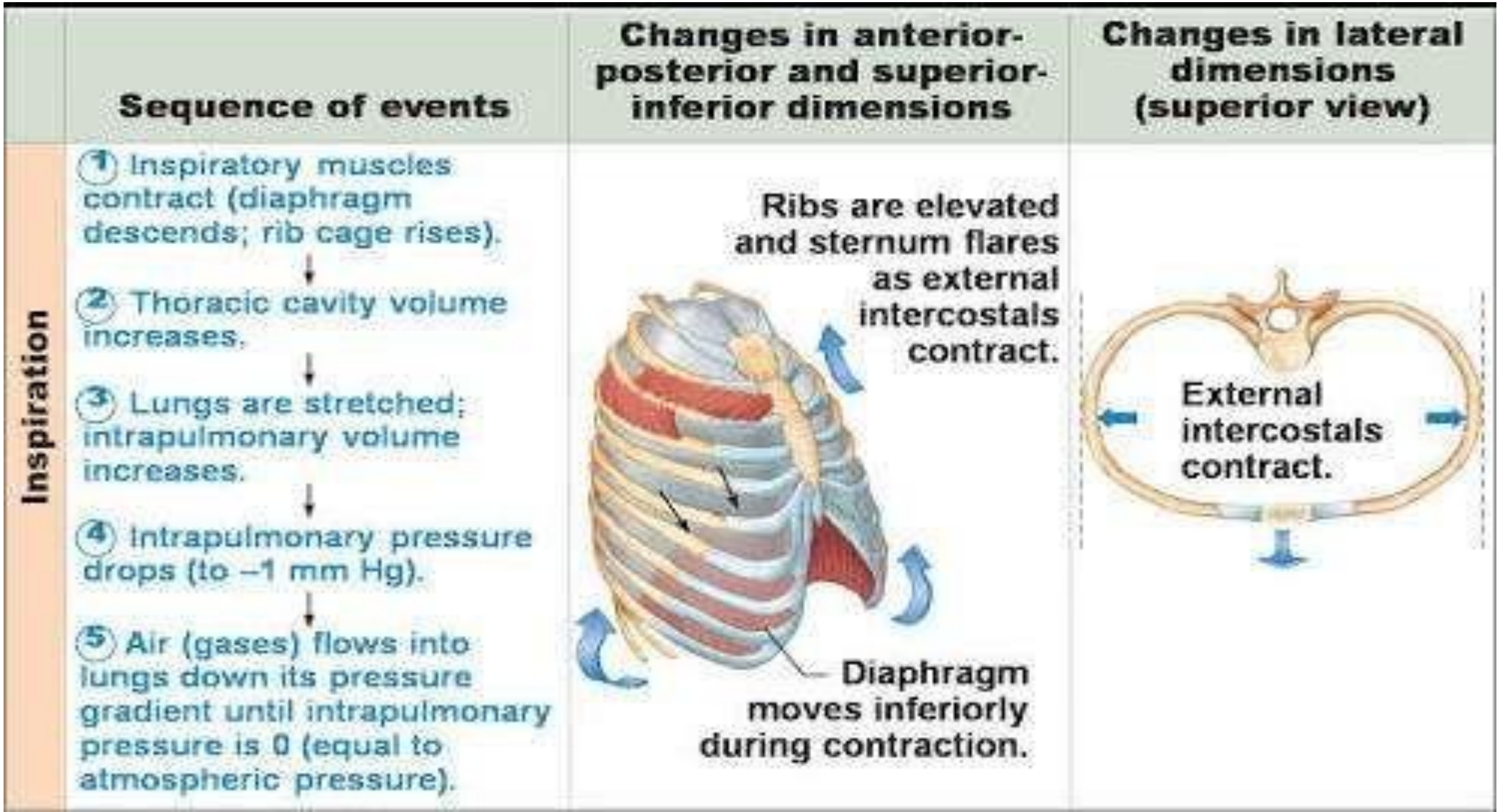
- External intercostal muscles are present obliquely between ribs in forward and downward direction. Their attachment to lower ribs is more forward from the axis of rotation.
- Therefore, contraction of external intercostal muscles raises the lower rib adequately.
- Contraction of external intercostal muscles has two effects:
- Bucket-handle effect: increases the transverse diameter of the thoracic cavity.
- Pump-handle effect : increases the vertical diameter of thoracic cage though antero- posterior diameter also increases to some extent.



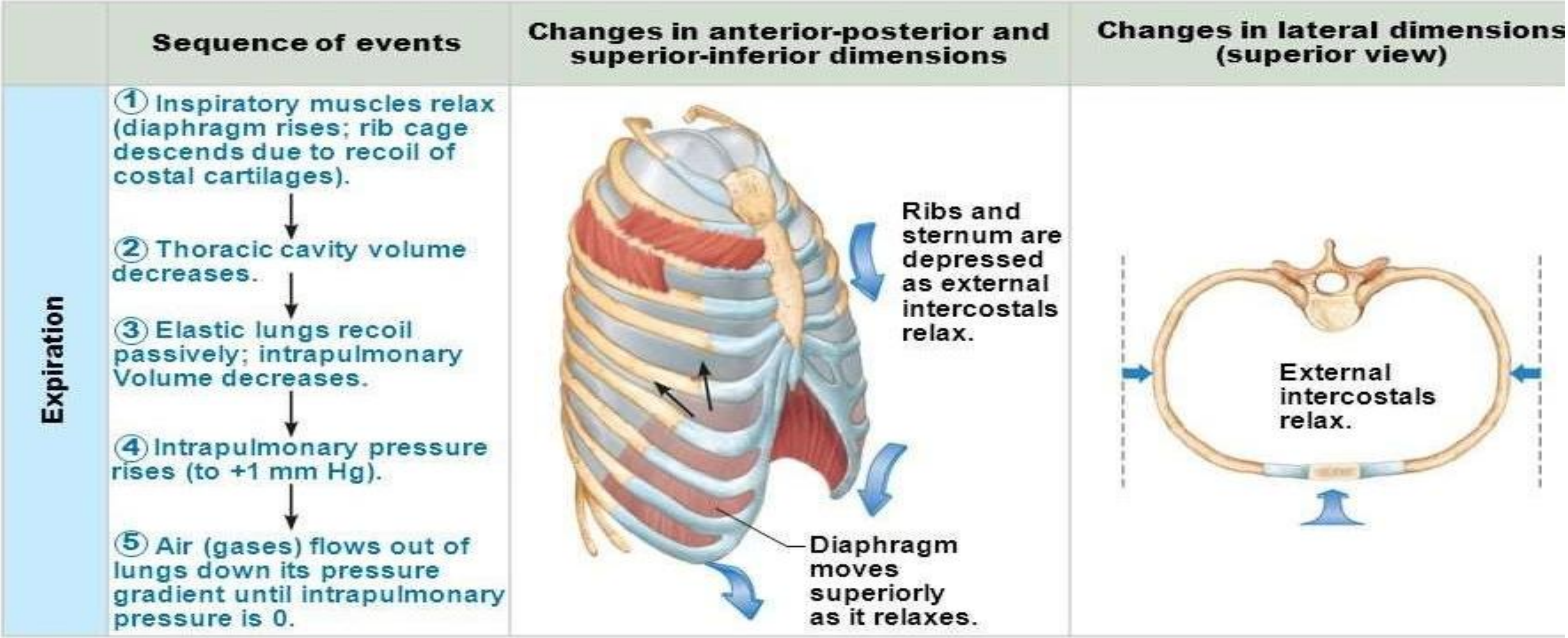
Overall effect during Inspiration and expiration



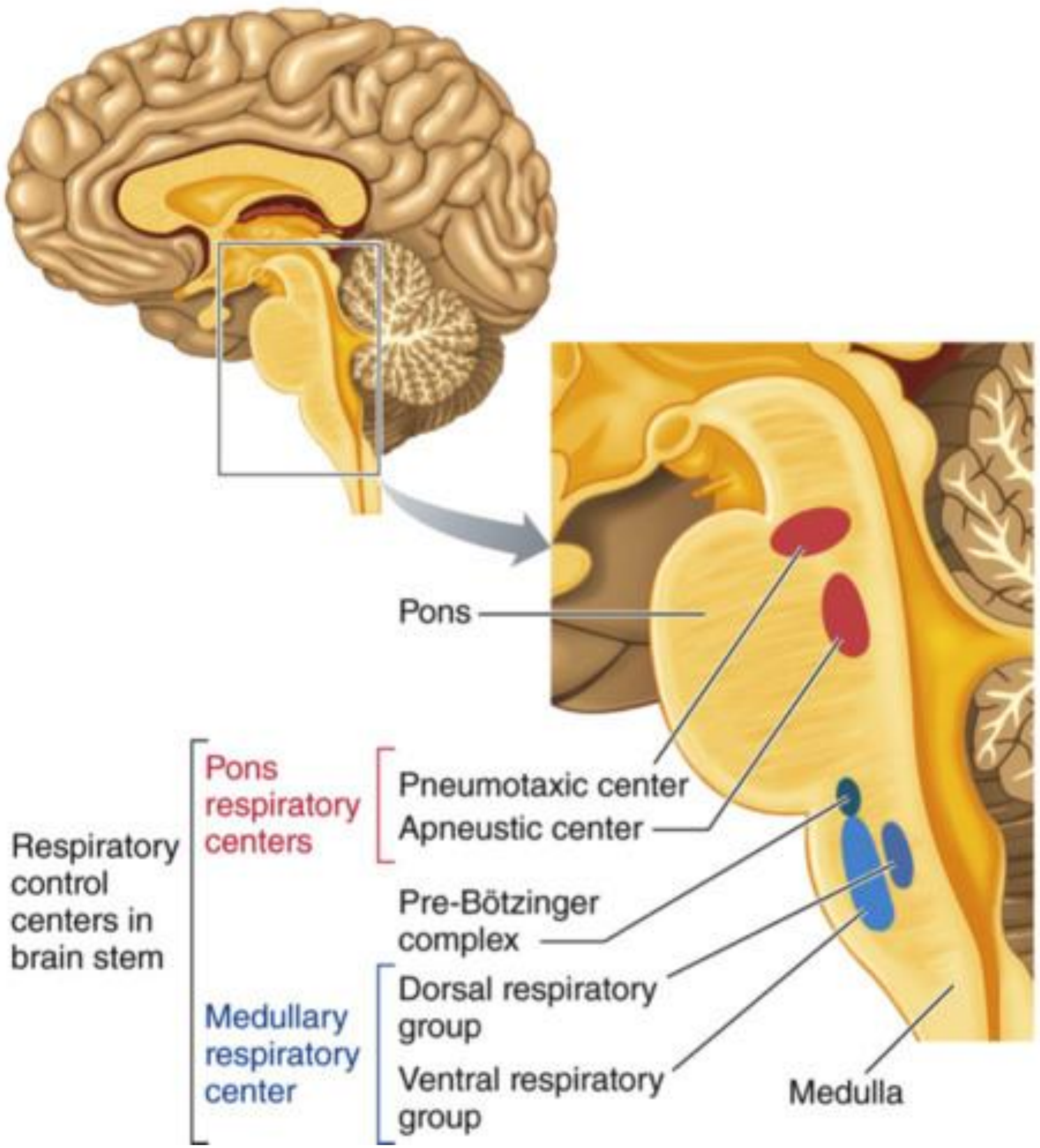
Inspiration

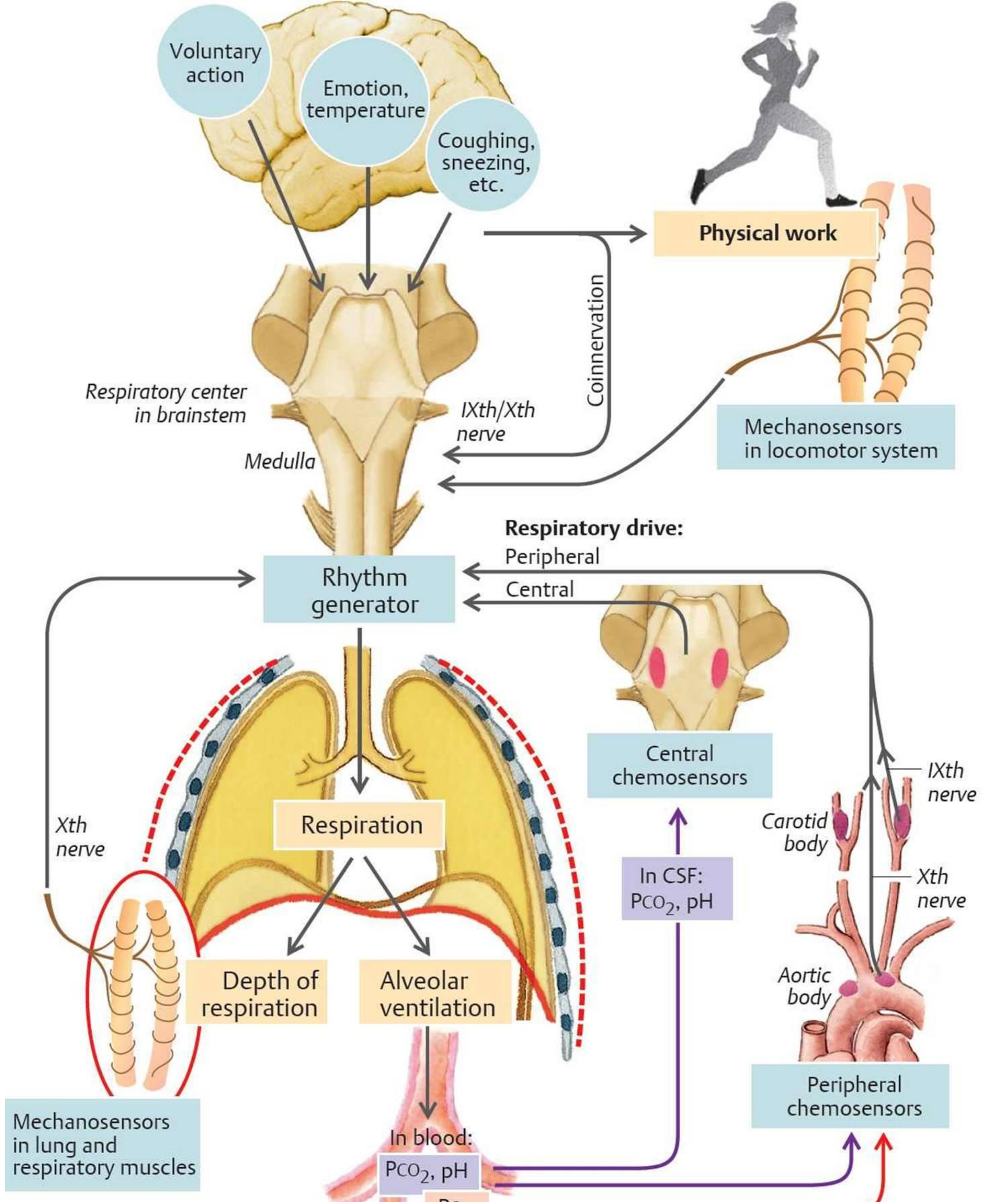


Expiration


Sequence of events
Changes in anterior-posterior and superior-inferior dimensions
Changes in lateral dimensions (superior view)
Expiration
1 Inspiratory muscles relax (diaphragm rises; rib cage descends due to recoil of costal cartilages).
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.
Ribs and sternum are depressed as external intercostals relax.
Diaphragm moves superiorly as it relaxes.
External intercostals relax.

Neural control of breathing





Continue..

- Ventral respiratory group – it contains I and E neuron. During eupnea the I neuron circuit fires for about 2 minutes. This causes contraction of diaphragm and external intercoastal muscles, causing inspiration and inhibition of expiration.
- After 2 minute I neuron wanes and E get excited and fires for 3 minutes causing exhalation.
- This process continues and gives 12 breaths per minutes.
- Dorsal Respiratory group – It modifies VRG based on output from other points.
- Pontine Respiratory group – DRG and ERG
- Central chemoreceptor, peripheral chemoreceptor, stretch receptor, irritant receptor
- Ondine’s Curse

Movements of Lungs

Collapsing tendency of lungs

1. Elastic property
2. Surface tension

Factors preventing collapsing

1. Intrapleural pressure – always negative
2. Surfactant – lipoproteins
3. Adult respiratory distress syndrome- lungs filled with liquid making breathing difficult.

1mmHg=13.6mmH2o =1.4cm H2o

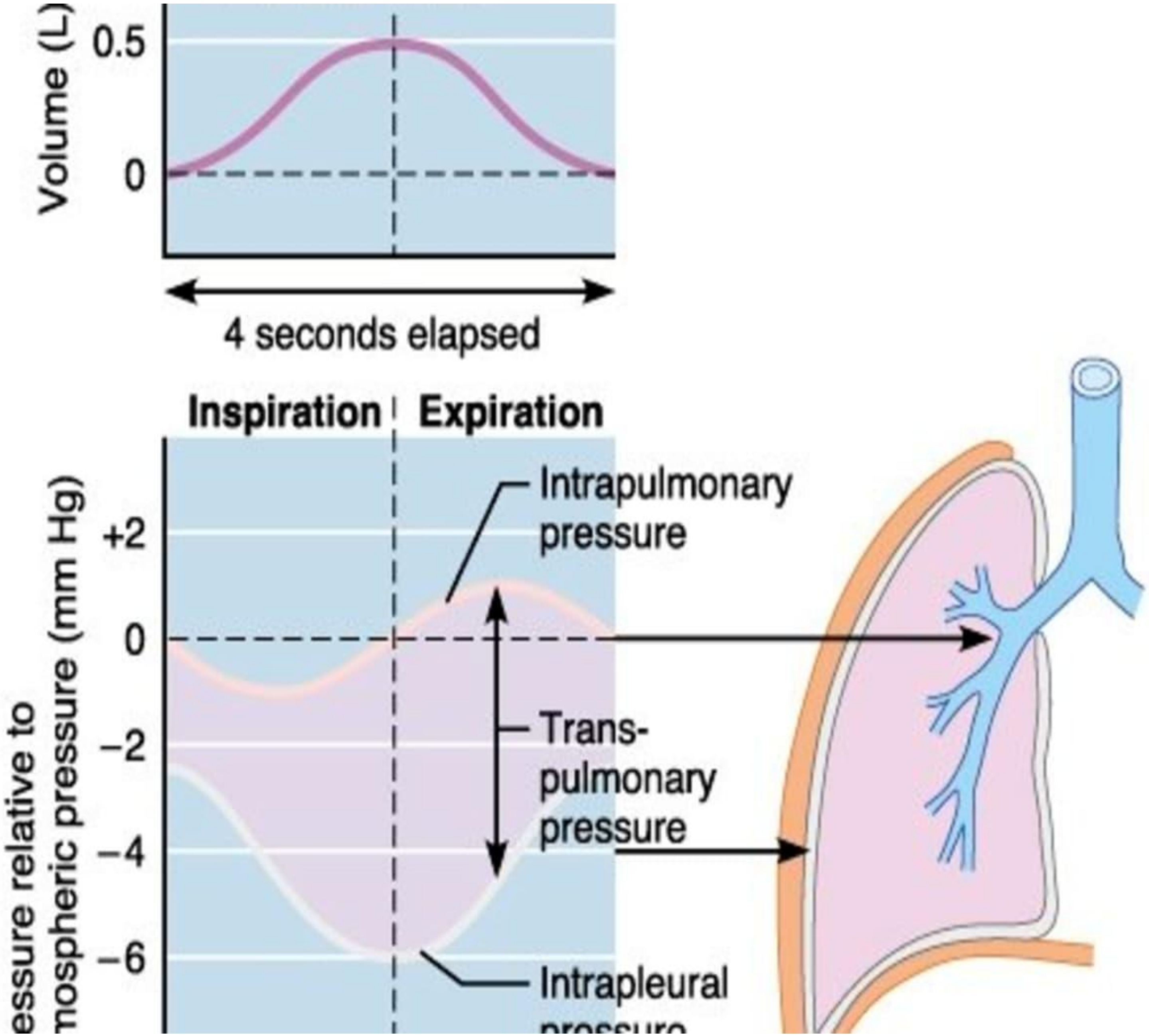
$F \alpha \Delta P/R$

Respiratory Gas Laws

Boyle's Law[9]	The pressure of a given quantity of gas is inversely proportional to its volume (assuming a constant temperature).
Charles' Law[10]	The volume of a given quantity of gas is directly proportional to its absolute temperature (assuming a constant pressure).
Dalton's Law[11]	The total pressure of a gas mixture is equal to the sum of the partial pressures of its individual gases.
Henry's Law[12]	At the air-water interface, the amount of gas that dissolves in water is determined by its solubility in water and its partial pressure in the air (assuming a constant temperature).

Respiratory pressure

- Changes in different pressures in the thoracic cavity that result in breathing are
- Intrapleural pressure
- Transmural pressures
- Alveolar pressure



INTRAPLEURAL PRESSURE

- The pressure in the pleural space is the intarpleural pressure. The pleural space is the space between the lungs and the chest wall, i.e. the virtual space between the visceral and parietal pleura. The pumping of fluid from the peural cavity into the lymphatic system makes it negative.

- Normal value: in quiet breathing , the intrapleural pressure during expiration is about -2.5 to -4mm of Hg and during inspiration is about -6mm of Hg. However, during forced expiration , intrapleural pressure becomes positive and during forced inspiration it becomes further negative , may be upto-30 mm of Hg

- SIGNIFICANCE OF INTRAPLEURAL PRESSURE
- Loss of normal intrapleural pressure results in lung collapse and barrel shaped chest.

TRANSMURAL PRESSURES

- Transmural pressure is the pressure difference across a airway or across the lung wall.
- It is measure of elastic tendency of lungs.
- Keeps the lung inflated and prevents the lungs from collapsing

ALVEOLAR PRESSURE

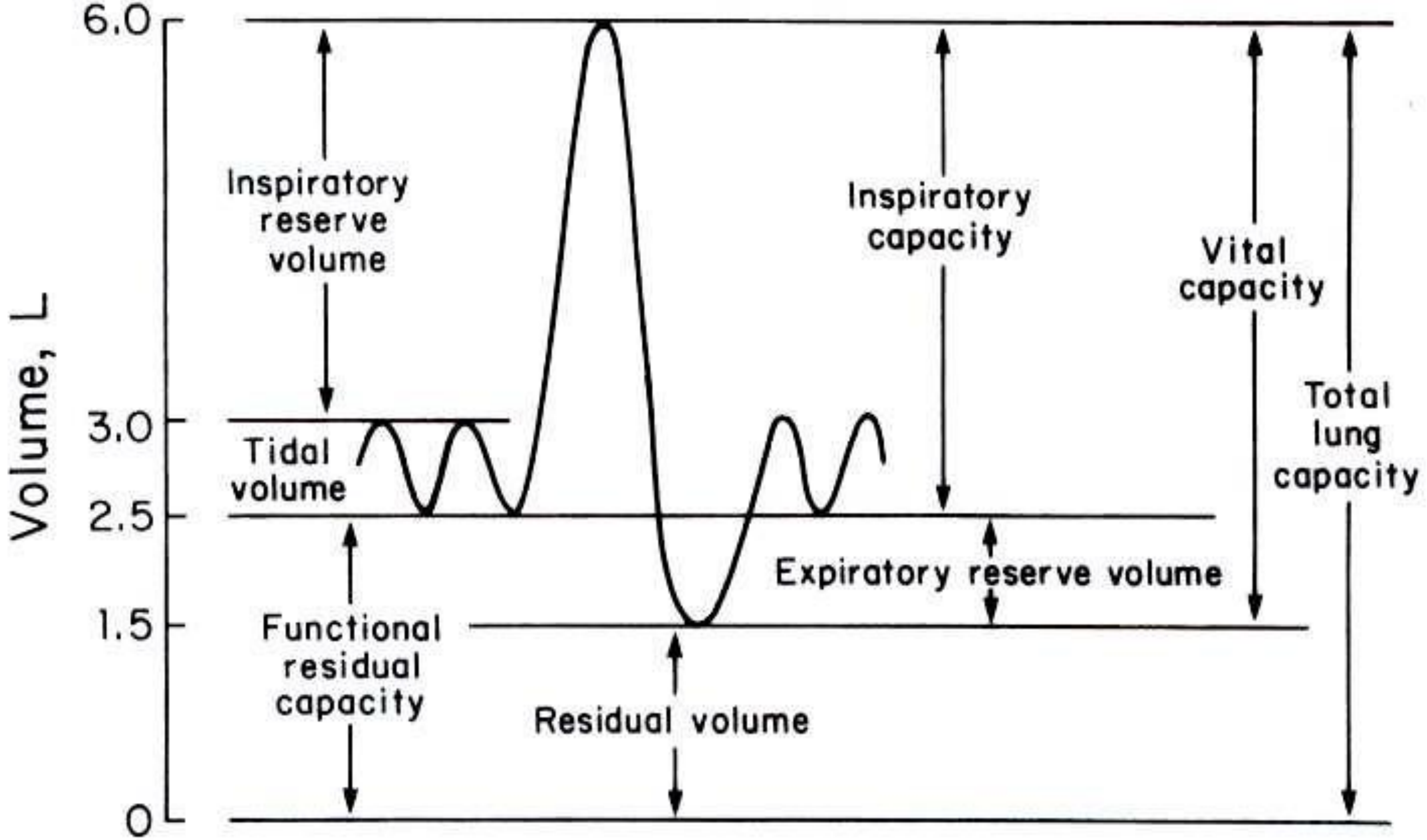
- The alveolar pressure is the pressure inside the alveoli. Change in alveolar pressure moves air in and out of the lungs. During inspiration, alveolar pressure decreases that sucks air into the lungs and during expiration the alveolar pressure increases that removes the air from the lungs.
- Normal value: during inspiration it is approximately -1mmHg and during expiration +1mmHg

Alveolar Ventilation

- Anatomical dead space- conducting zone-150mL
- Alveolar ventilation rate= 350mL x 12 breaths/min= 4,200mL/min.
- Bulk flow of air gets only as far as terminal bronchioles. Beyond this this point, air passage is so narrow and flow resistance is so great.
- O_2 completes its journey and CO_2 leaves them by simple diffusion.
- Residual volume – 1300mL – that one cannot exhale even with maximum effort.
- It takes about 90 sec or 18 breaths at an average rate and depth of breathing to completely replace all pulmonary air.

Lung Volumes & Capacities

Respiratory Volumes and Capacities for an Average Young Adult Male		
Measurement	Typical Value	Definition
Respiratory Volumes		
1 Tidal volume (TV)	500 ml	Amount of air inhaled or exhaled in one breath during relaxed, quiet breathing
2 Inspiratory reserve volume (IRV)	3000 ml	Amount of air in excess of tidal inspiration that can be inhaled with maximum effort
3 Expiratory reserve volume (ERV)	1200 ml	Amount of air in excess of tidal expiration that can be exhaled with maximum effort
4 Residual volume (RV)	1200 ml	Amount of air remaining in the lungs after maximum expiration; keeps alveoli inflated between breaths and mixes with fresh air on next inspiration
Respiratory Capacities		
5 Vital capacity (VC)	4700 ml	Amount of air that can be exhaled with maximum effort after maximum inspiration (ERV + TV + IRV); used to assess strength of thoracic muscles as well as pulmonary function
6 Inspiratory capacity (IC)	3500 ml	Maximum amount of air that can be inhaled after a normal tidal expiration (TV + IRV)
7 Functional residual capacity (FRC)	2400 ml	Amount of air remaining in the lungs after a normal tidal expiration (RV + ERV)
8 Total lung capacity (TLC)	5900 ml	Maximum amount of air the lungs can contain (RV + VC)


6.0
3.0
2.5
1.5
0
Volume, L
Inspiratory reserve volume
Tidal volume
Functional residual capacity
Residual volume
Inspiratory capacity
Expiratory reserve volume
Vital capacity
Total lung capacity

Spirometer

- Spirometer: captures the expired breath and records such variables as the rate and depth of breathing, speed of expiration and rate of oxygen consumption.
- Spirometer helps to assess and distinguish restrictive and obstructive diseases.

OBSTRUCTIVE VS. RESTRICTIVE

Obstructive disorders	Restrictive disorders
• **Characterized by:** reduction in airflow. • So, shortness of breath → in exhaling air. (the air will remain inside the lung after full expiration) 1. COPD 2. Asthma 3. Bronchiectasis	• **Characterized by** a reduction in lung volume. • So, Difficulty in taking air inside the lung. (DUE TO stiffness inside the lung tissue or chest wall cavity) 1. Interstitial lung disease. 2. Scoliosis 3. Neuromuscular cause 4. Marked obesity

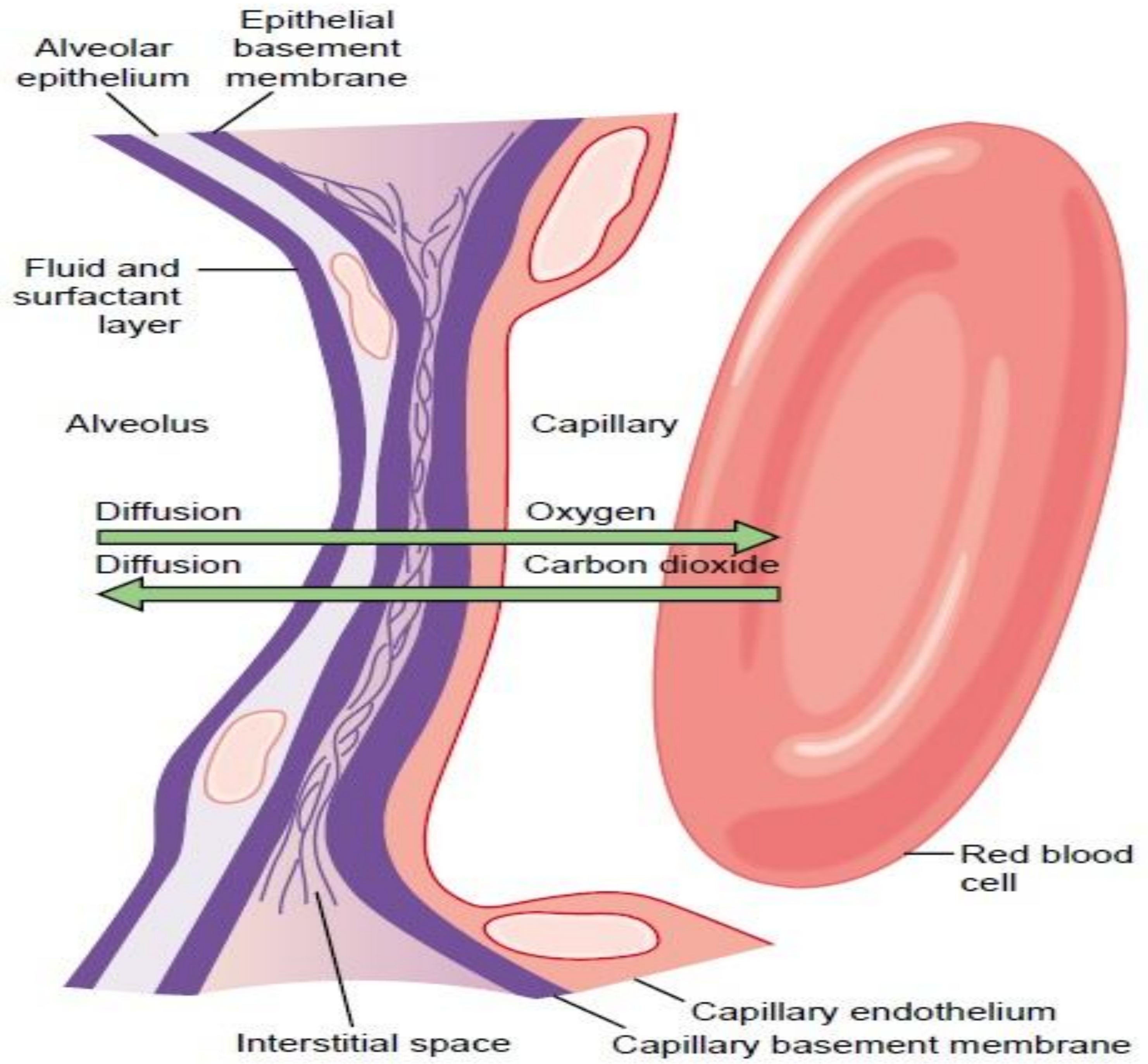
Exchange of gases

- Exchange of gases takes place between the alveoli and the blood.
- It happens at respiratory unit. It basically depends upon 3 factors:
  - Respiratory membrane- formed by different layers of alveoli and capillaries.
  - Diffusing capacity of lungs
  - Diffusion of O_2 and CO_2

Membrane

It is made up of 6 layers
From Alveolar portion-

1. Monomolecular layer of surfactants, which spreads over the surface of the fluid lining of alveoli.
2. A thin layer of fluid that lines the alveoli
3. The alveolar epithelial layer, which consists of thin epithelial cells resting on basement membrane.
4. An interstitial space
5. Basement membrane of capillary
6. Capillary endothelial cells



Gas Exchange

Respiratory Membrane (Air-Blood Barrier)

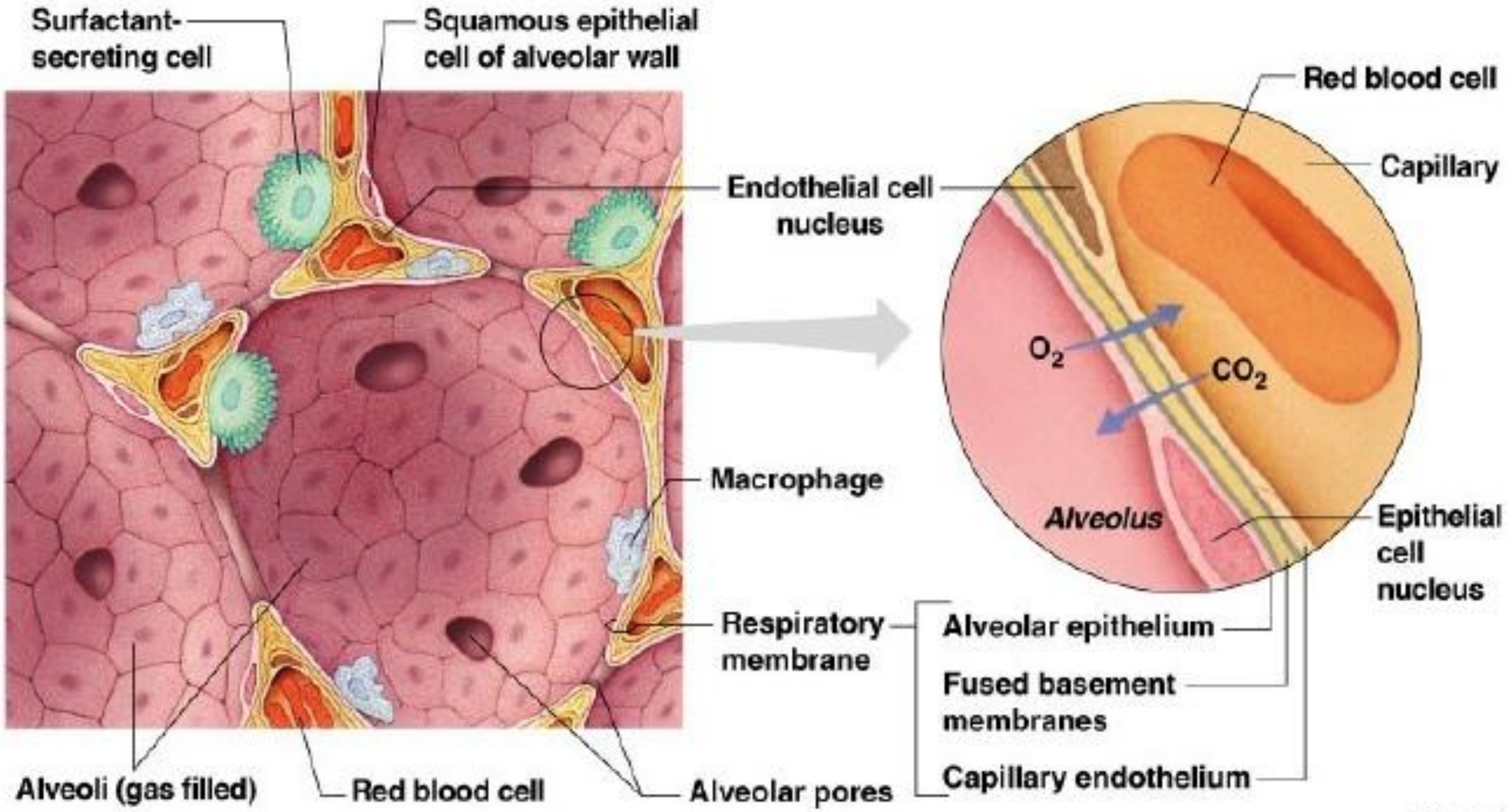


Figure 13.6

Diffusing capacity of lung

- Diffusion capacity is defined as the volume of gas that diffuses through the respiratory membrane each minute for a pressure gradient of 1 mm Hg.
- For O_2= 21ml/minute/1mmHg
- For CO_2= 400ml/minute/1mmHg
- Factors affecting diffusion capacity

Quantifying the Net Rate of Diffusion in Fluids

- factors affect the rate of gas diffusion in a fluid:

1. the pressure difference.
2. the solubility of the gas in the fluid,
3. the cross-sectional area of the fluid,
4. the distance through which the gas must diffuse,
5. the molecular weight of the gas,
6. the temperature of the fluid.

- All these factors can be expressed in a single formula, as follows:

$$\boxed{D \propto \frac{\Delta P \times A \times S}{d \times \sqrt{MW}},}$$

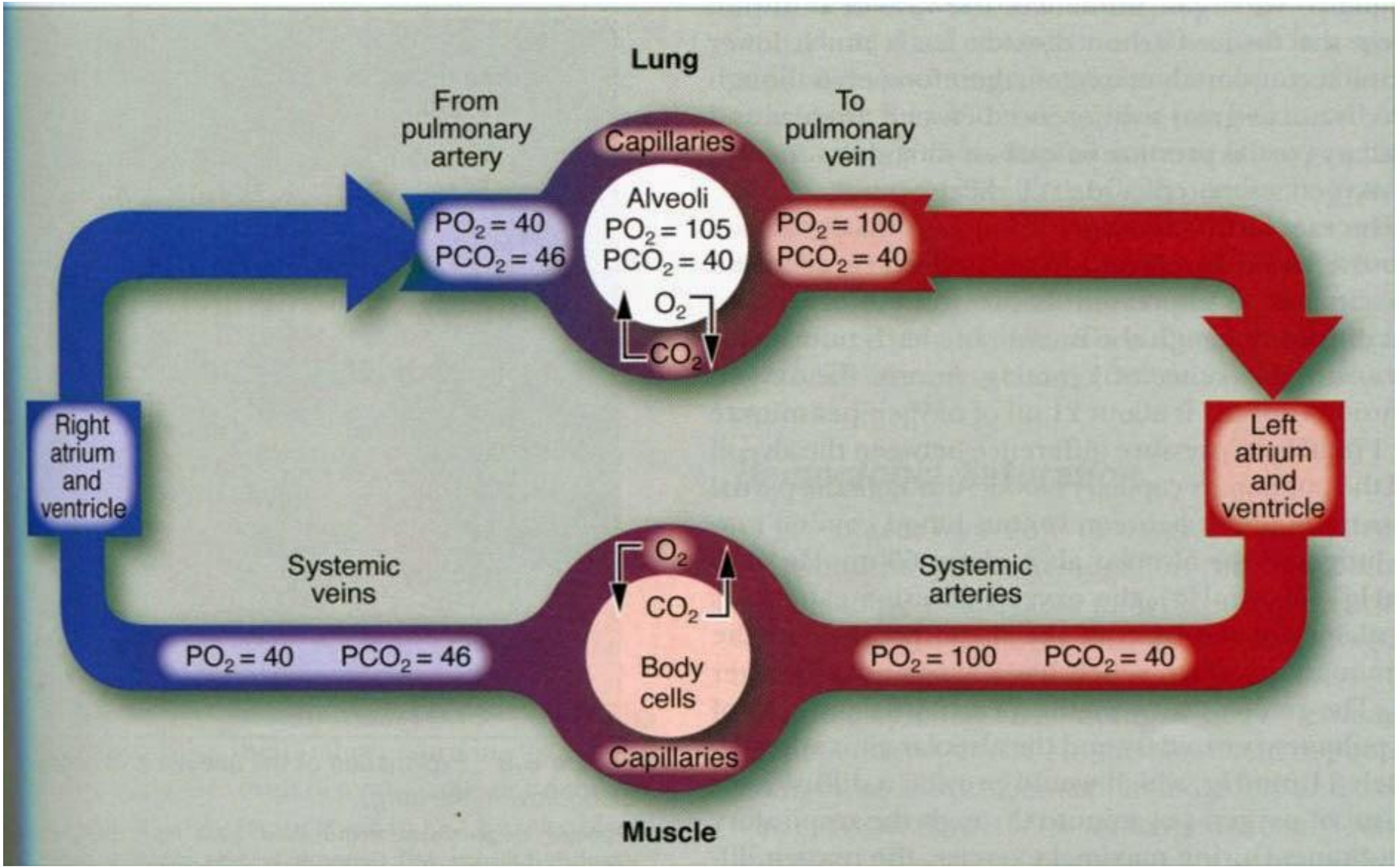
Diffusion of Oxygen and carbon dioxide

Direction of diffusion of oxygen

Respiratory gas	Partial pressure of Oxygen (mmHg)
Atmospheric air	159
Alveoli	104
Oxygenated blood	95
Tissues	40

Direction of diffusion of carbon dioxide

Respiratory gas	Partial pressure of Carbon dioxide (mmHg)
Atmospheric air	0.3
Alveoli	40
Deoxygenated blood	45
Tissues	45



Lung
From pulmonary artery
Capillaries
To pulmonary vein
Alveoli
PO2 = 105
PCO2 = 40
PO2 = 40
PCO2 = 46
PO2 = 100
PCO2 = 40
O2
CO2
Right atrium and ventricle
Left atrium and ventricle
Systemic veins
Systemic arteries
O2
CO2
PO2 = 40 PCO2 = 46
PO2 = 100 PCO2 = 40
Body cells
Capillaries
Muscle

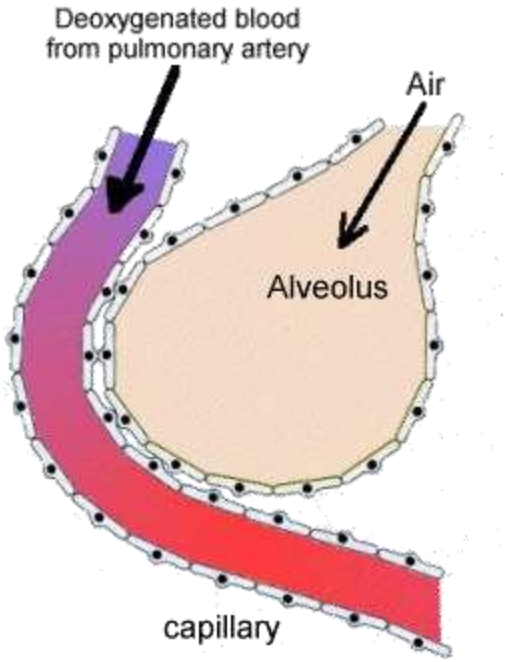
Ventilation-Blood Flow Coupling

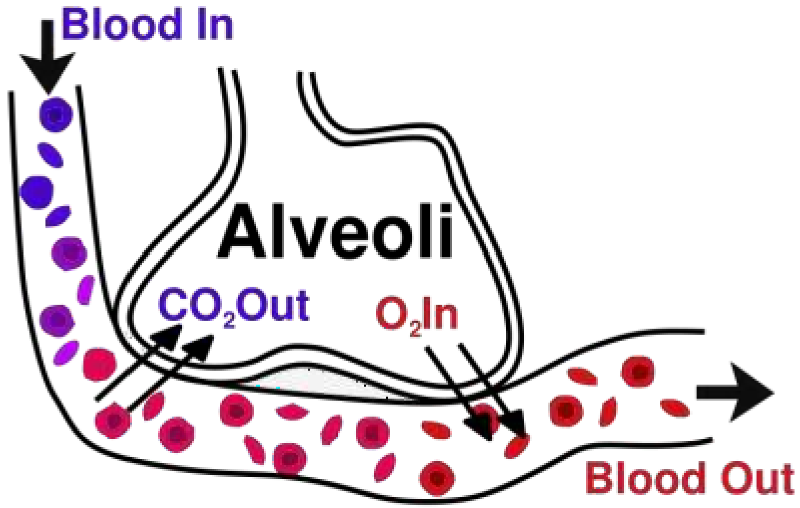
Low O_2 in alveolus ⟶ vasoconstriction

High O_2 in alveolus ⟶ vasodilation

High CO_2 in alveolus ⟶ dilate bronchioles

Low CO_2 in alveolus ⟶ constrict bronchioles





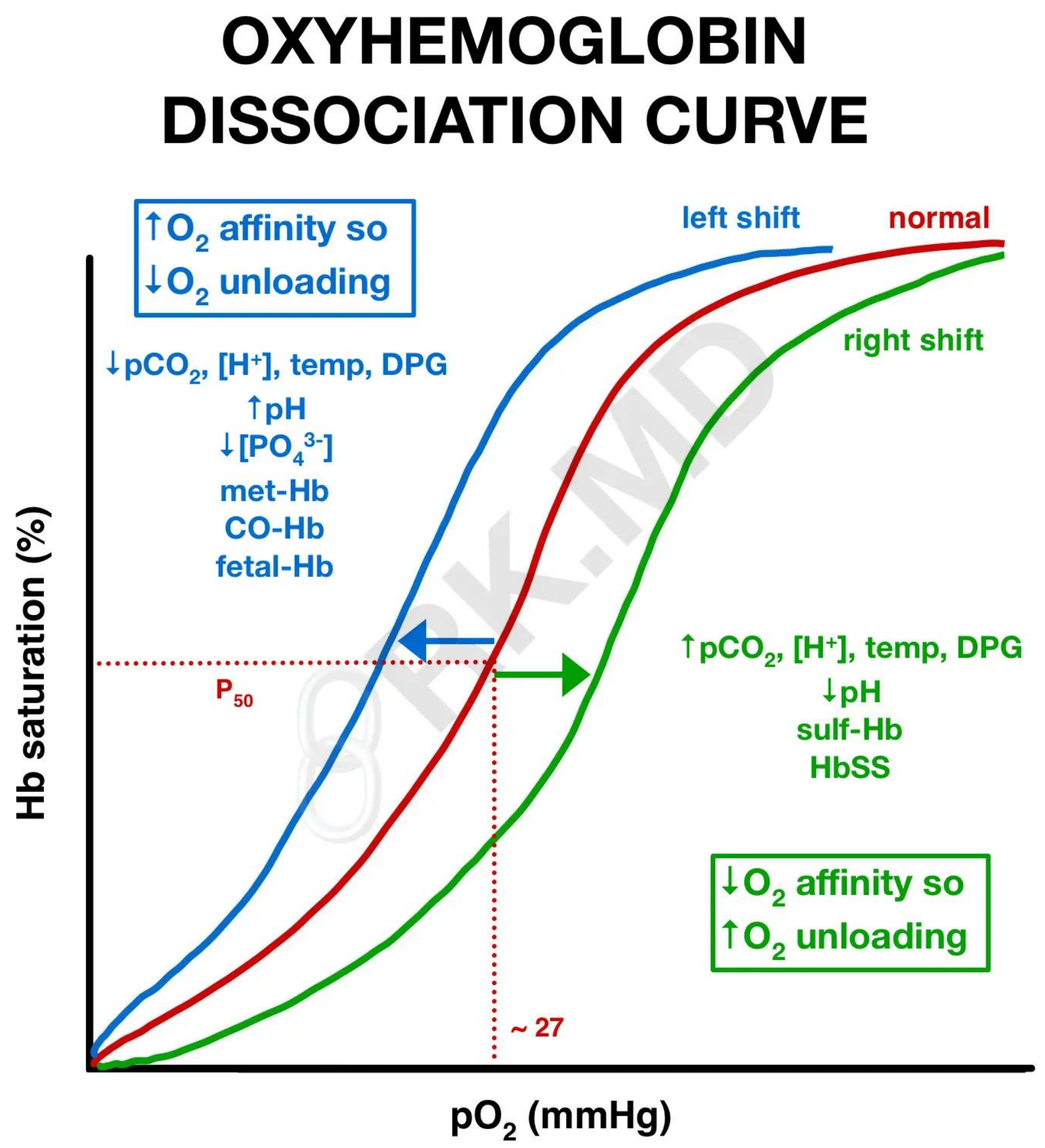
Transport of Oxygen

- Transport of O2:

  i) As simple solution (3% i.e. 0.3ml/100ml)- O2 dissolved in water of plasma and is transported in this physical form. It is because of poor solubility of oxygen in water. But it is important during the muscular exercise to meet excess demand of oxygen by the tissue.

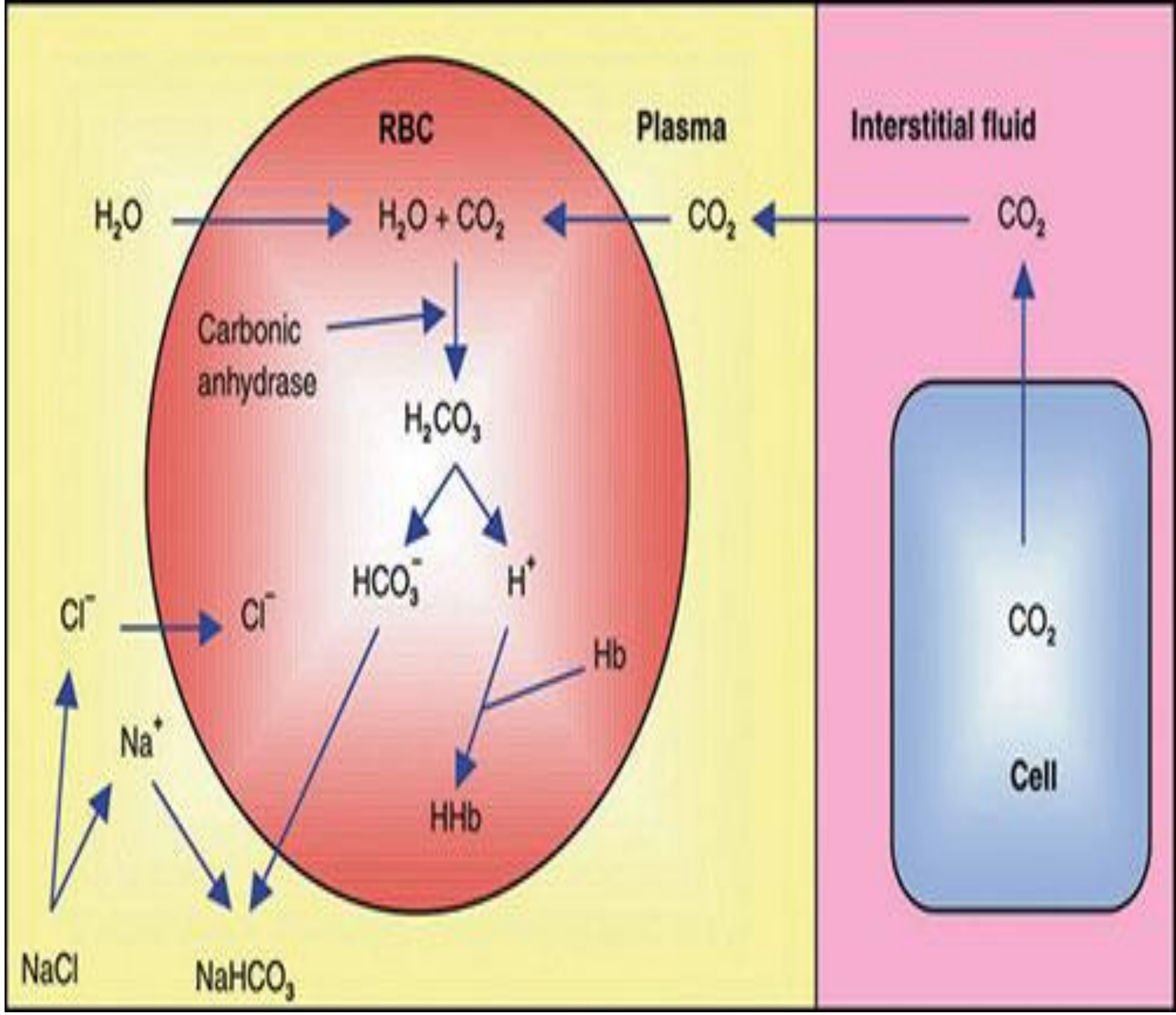
  ii) In Combination with Hb (97%)- O2 combines with haemoglobin in blood and is transported as oxyhaemoglobin.

Oxygen carrying capacity of blood : it refers to the amount of oxygen transported by blood. 1 gm of haemoglobin carries 1.34 mL of oxygen. It is called oxygen carrying capacity of haemoglobin.



Transport of CO2

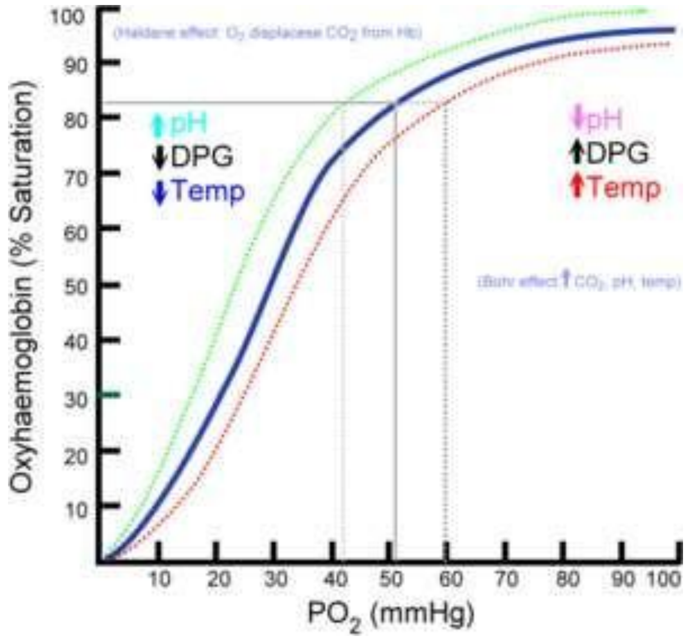
- Transport of CO2:
  i) As dissolved form (7%)
  ii) As carbonic Acid (Negligible)
  iii) As Bicarbonate (63%)
  iv) As Carbamino Compounds (30%)- Carbaminohemoglobin(HbCO 2)

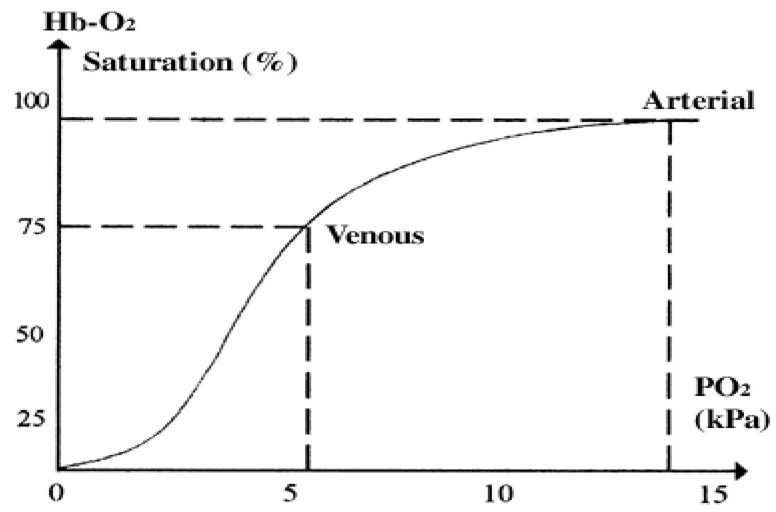


- Oxygen Dissociation Curve

1. Oxygen-hemoglobin dissociation curve

- a. 104 mm (lungs) - 100% saturation (20 ml/100 ml)
- b. 40 mm (tissues) - 75% saturation (15 ml/100 ml)
- c. right shift - Decreased Affinity, more O_2 unloaded
- d. left shift- Increased Affinity, less O_2 unloaded





Haemoglobin-oxygen dissociation curve, showing the normal arterial and venous points.

Fig 8

A. Effects of Temperature

1. HIGHER Temperature → Decreased Affinity (right)
2. LOWER Temperature → Increased Affinity (left)

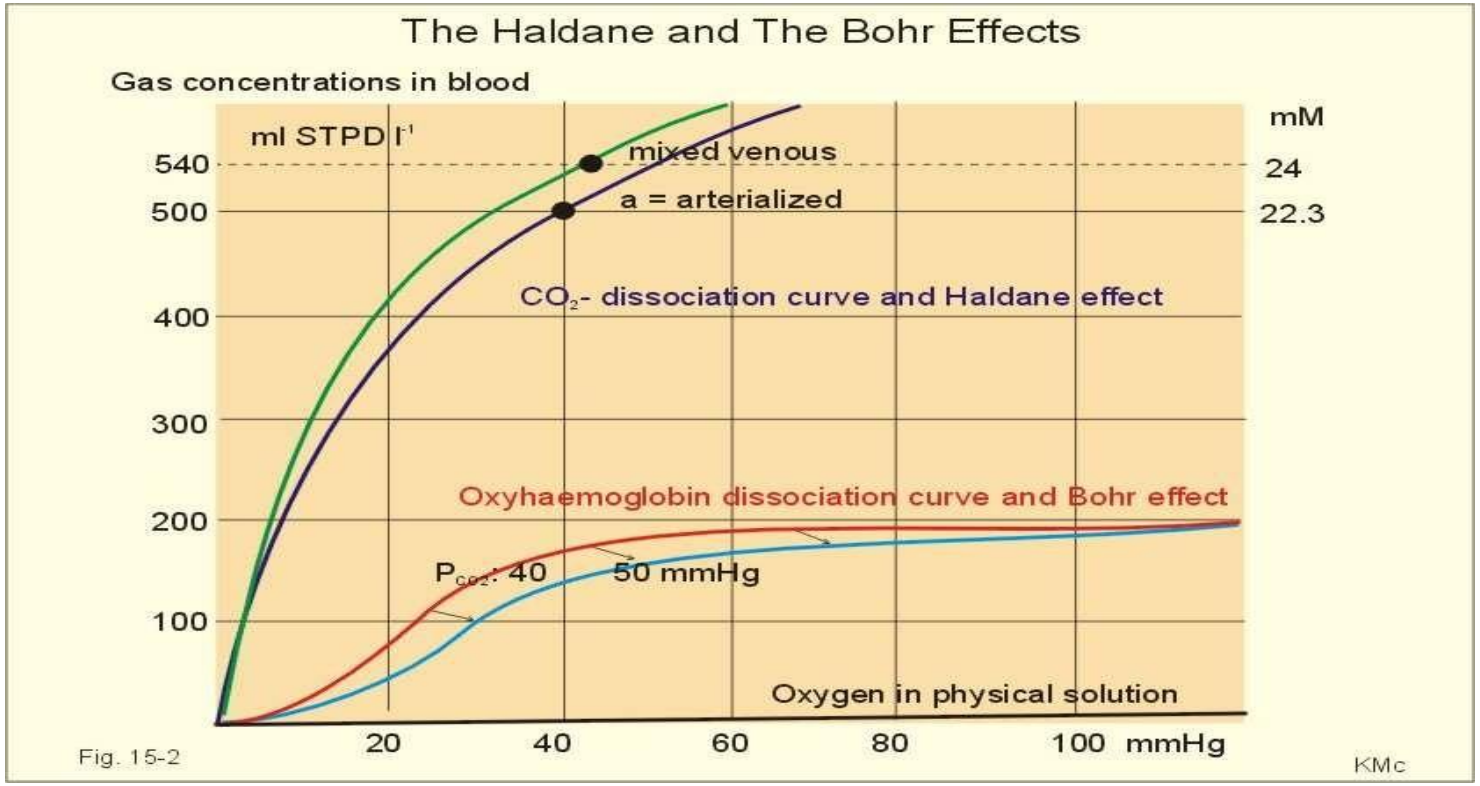
B. Effects of pH (Acidity)

1. HIGHER pH → Increased Affinity (left)
2. LOWER pH → Decreased Affinity (right) "Bohr Effect“

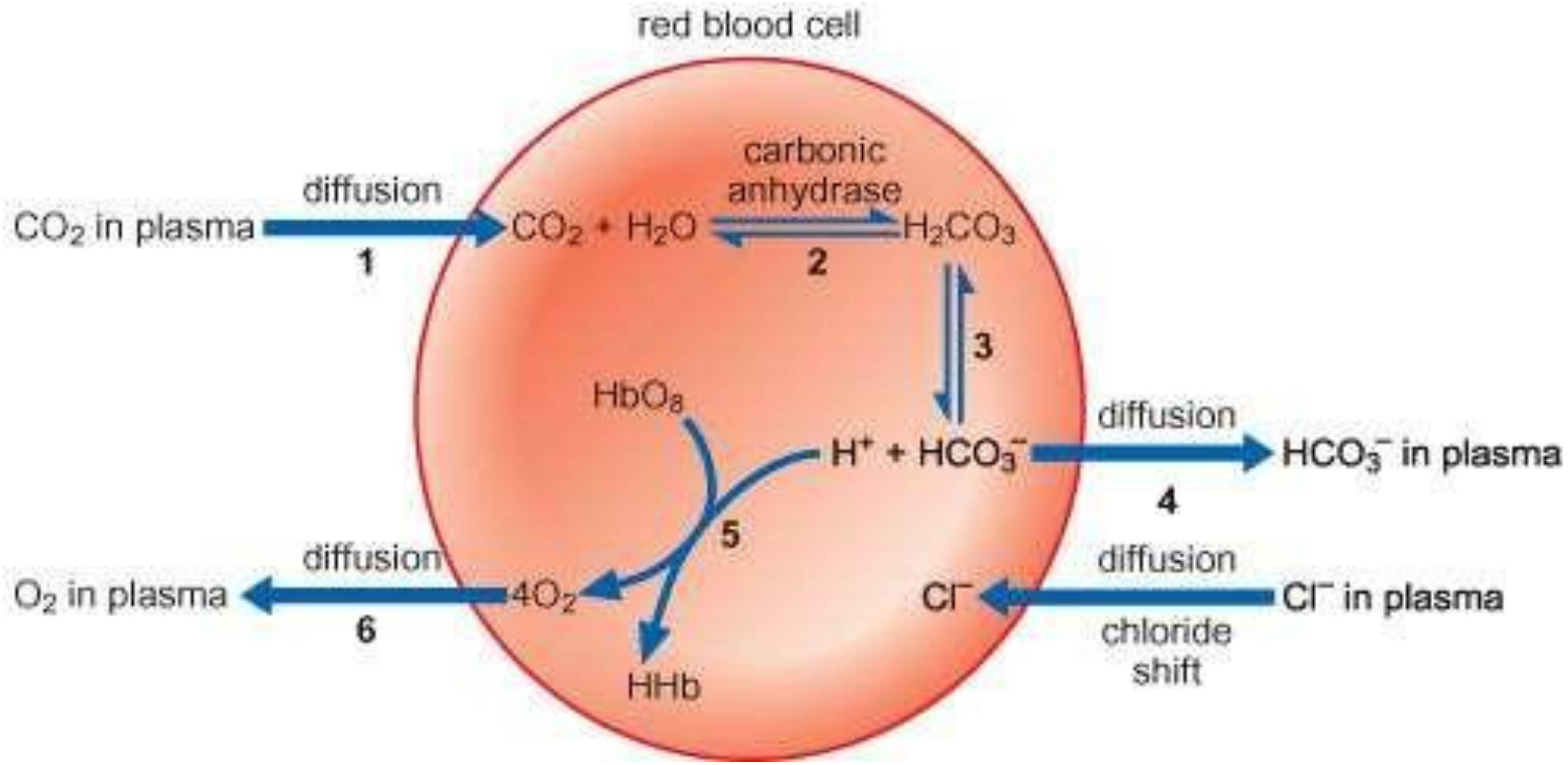
C. Effects of Diphosphoglycerate (DPG)

1. DPG - produced by anaerobic processes in RBCs
2. HIGHER DPG > Decreased Affinity (right)
3. Thyroxine, testosterone, epinephrine, NE - increase RBC metabolism and DPG production, cause RIGHT shift.

- Carbon Dioxide Dissociation Curve
- Bohr Effect - Formation of Bicarbonate (through Carbonic Acid) leads to LOWER pH (H+ increase), and more unloading of Ox to tissues. Since Hb "buffers" to H^+, the actual pH of blood does not change much.



- Chloride Shift - Chloride ions move in opposite direction of the entering/leaving Bicarbonate, to prevent osmotic problems with RBCs



Regulation of Respiration

Nervous Mechanism

A. Medullary Respiratory

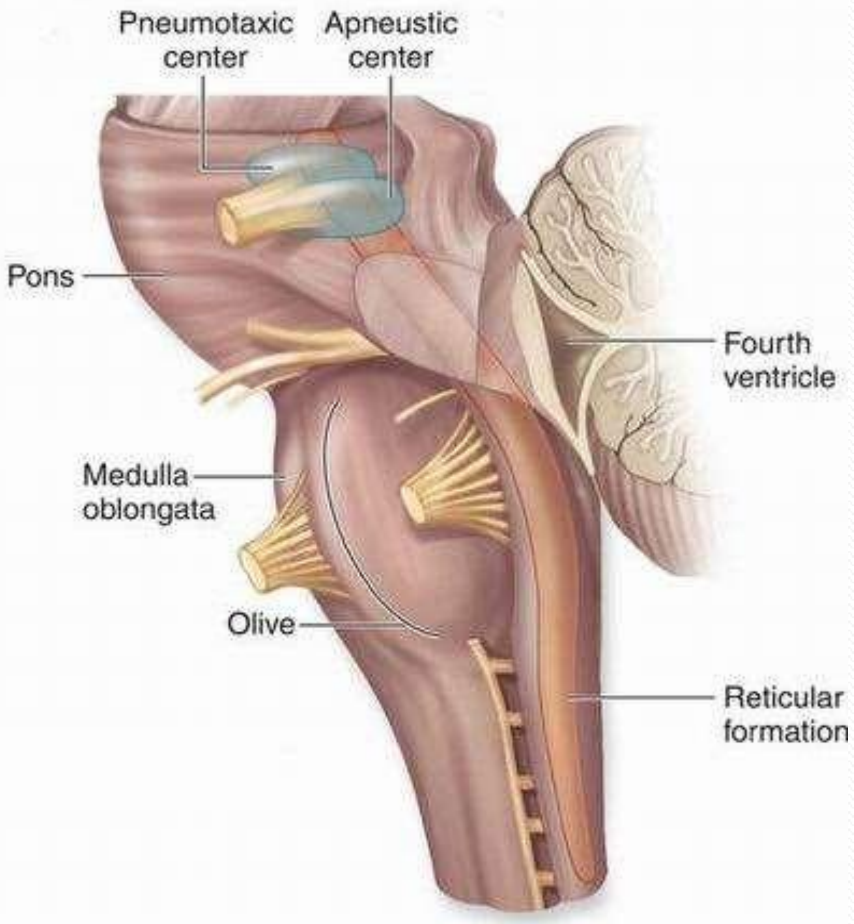
- **Inspiratory Center (Dorsal Resp Group - rhythmic breathing**
- Phrenic nerve, Intercostal nerves , diaphragm + external intercostals

- **Expiratory Center (Ventral Resp Group - forced expiration)**
- Phrenic nerve, Intercostal nerves, Internal intercostals + abdominals (expiration)

1. Eupnea - normal resting breath rate (12/minute)
2. Drug overdose - causes suppression of Inspiratory Center

B. Pons Respiratory Centre

- 1. Pneumotaxic center - slightly inhibits medulla, causes shorter, shallower, quicker breaths
- 2. Apneustic center – stimulates the medulla, causes longer, deeper, slower breaths



C. Control of Rate & Depth of Breathing

- 1. Breathing rate - stimulation/inhibition of medulla.
- 2. Breathing depth - activation of inspiration muscles.
- 3. Hering-Breuer Reflex - stretch of visceral pleura that lungs have expanded (vagal nerve).

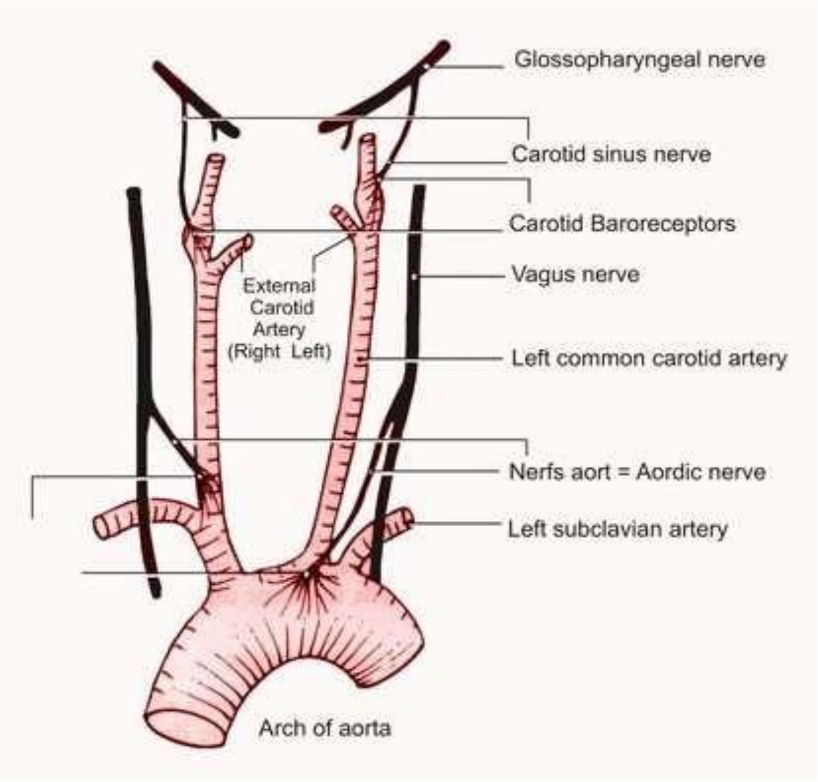
D. Hypothalamic Control - emotion + pain to the medulla

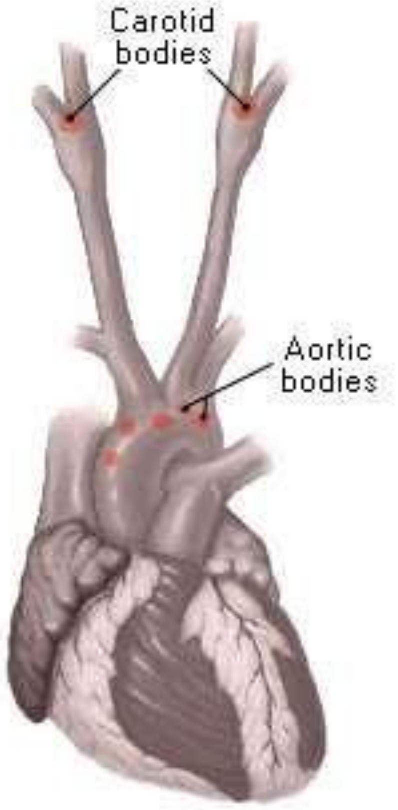
E. Cortex Controls (Voluntary Breathing) - can override medulla as during singing and talking

Chemical Mechanism

A. Chemoreceptors

- 1. Central chemoreceptors - located in the medulla
- 2. Peripheral chemoreceptors - large vessels of neck





B. Overview of Chemical Effects

Chemical	Breathing Effect
Increased CO_2 (more H^+)	Increase
Decreased CO_2 (less H^+)	Decrease
Slight decrease in O_2	Effects CO_2 system
Large decrease in O_2	Increases ventilation
Decreased pH (more H+)	Increase
Increased pH (less H+)	Decrease

Regulation of Respiration

Nervous Mechanism

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- **Expiratory Center (Ventral Resp Group - forced expiration)**
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1. Eupnea - normal resting breath rate (12/minute)
2.Drug

B. Pons Respiratory Centre

1. Pneumotaxic center - slightly inhibits medulla, causes shorter, shallower, quicker breaths
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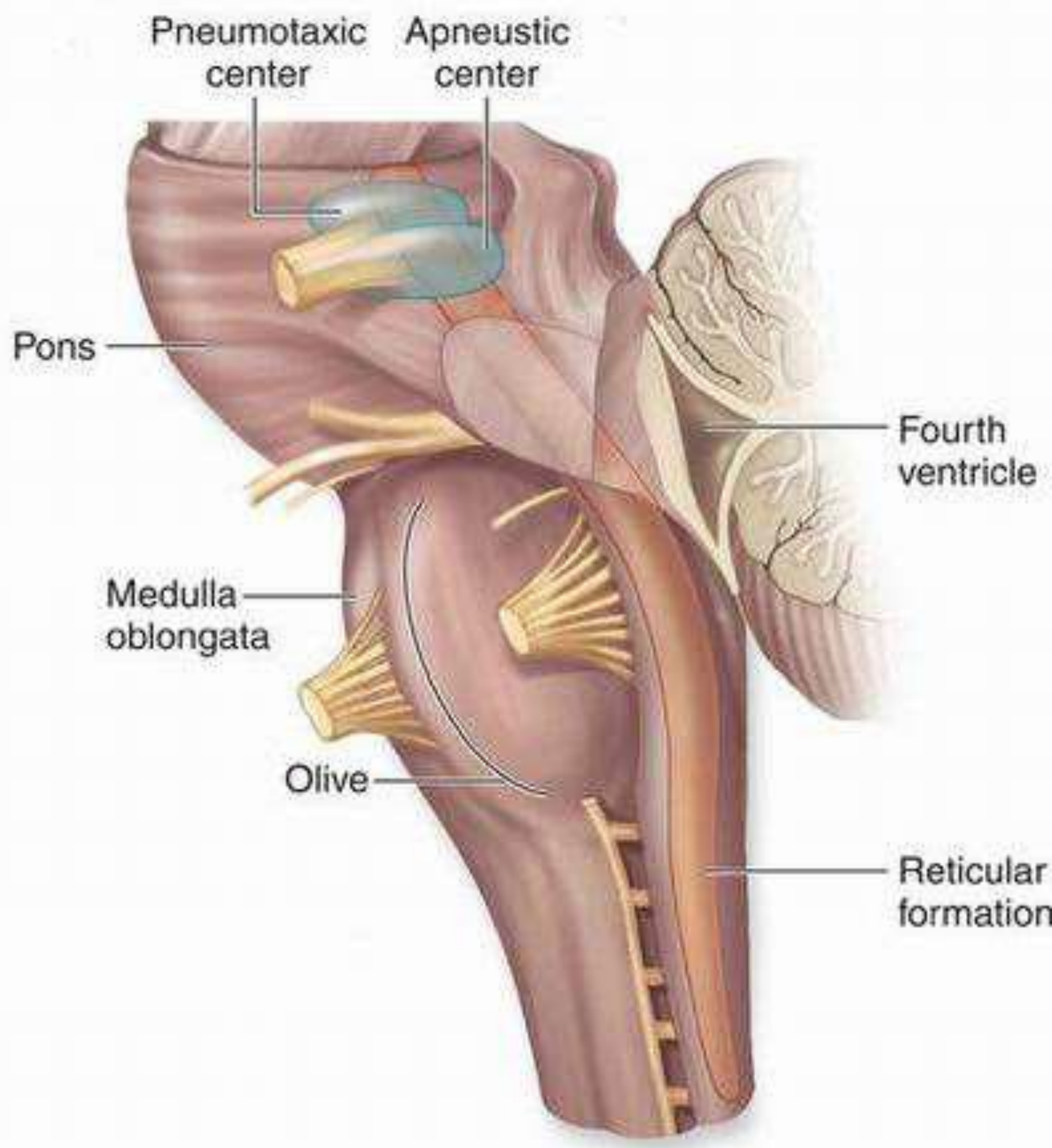

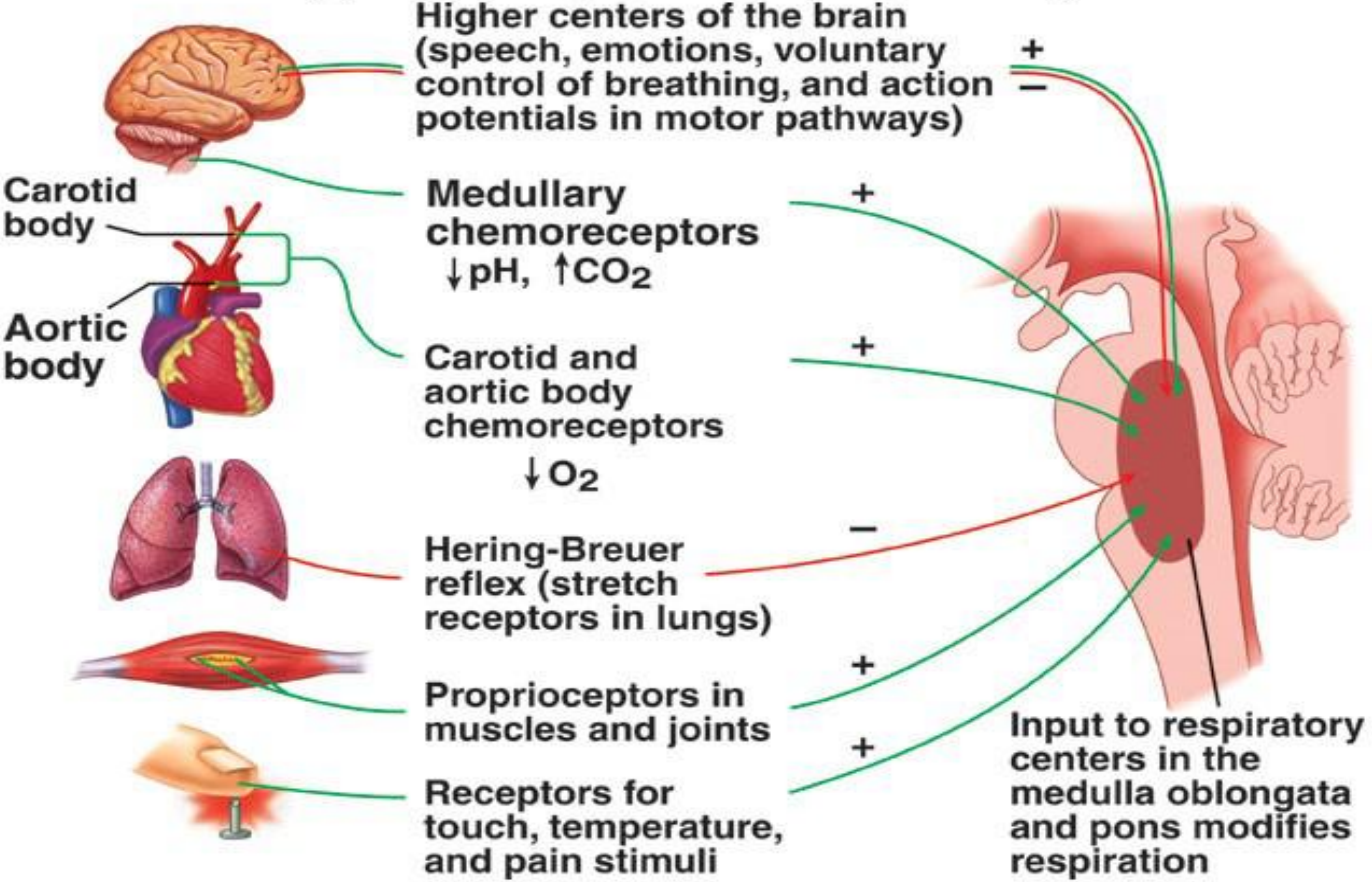
Higher centers of the brain (speech, emotions, voluntary control of breathing, and action potentials in motor pathways)
+
–
Carotid body
Aortic body
Medullary chemoreceptors
↓pH, ↑CO_2
+
Carotid and aortic body chemoreceptors
↓O_2
+
Hering-Breuer reflex (stretch receptors in lungs)
–
Proprioceptors in muscles and joints
+
Receptors for touch, temperature, and pain stimuli
+
Input to respiratory centers in the medulla oblongata and pons modifies respiration