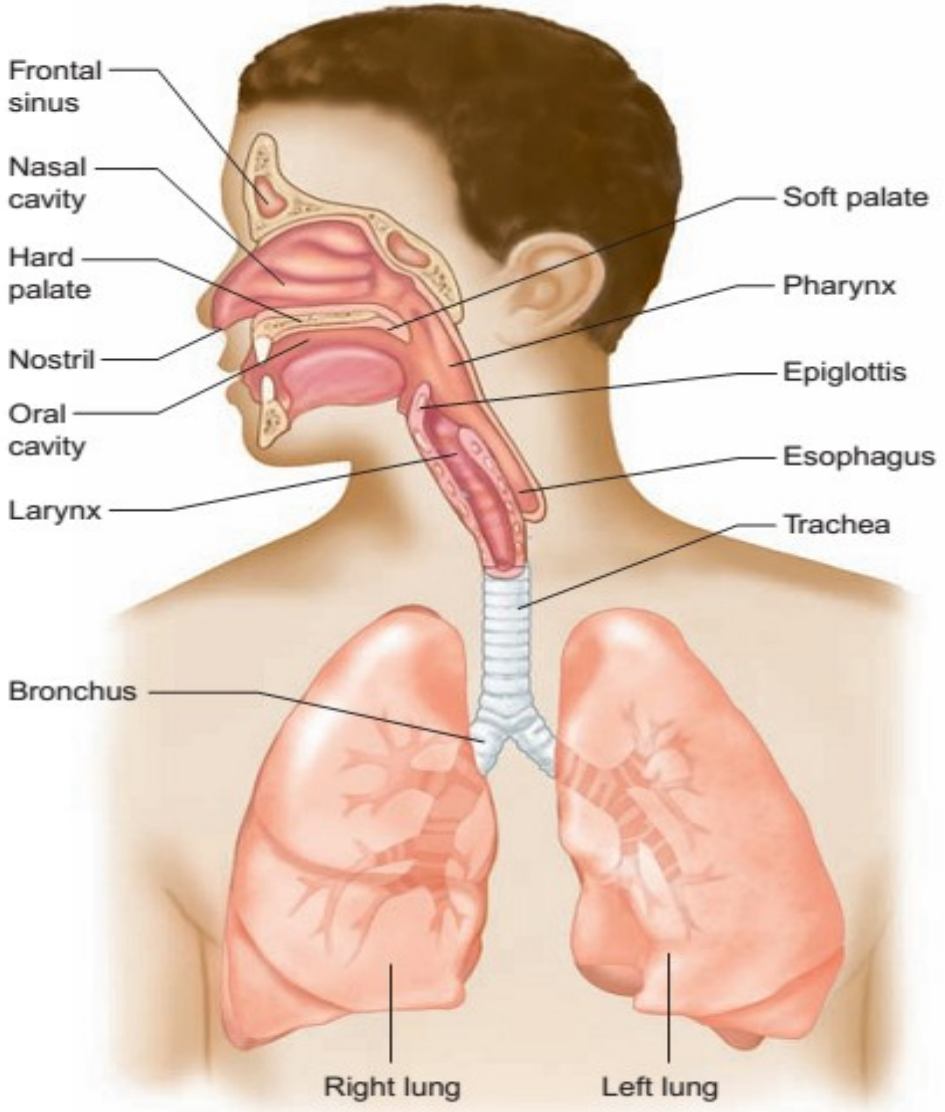
PHYSIOLOGY OF RESPIRATORY SYSTEM



Introduction

- Respiration is the entire process of gas exchange between the atmosphere and cells.
  - ✓ It is the process by which O_2 is taken in and CO_2 is given out.
- The first breath take place only after birth.
- Fetal lungs are non-functional.
  - ✓ So, during intrauterine life the exchange of gases between fetal blood and mother's blood occurs through placenta.
- After the first breath, the respiratory process continues

Introduction cont'd…

- There are four stage of respiration

1. Ventilation: is the mechanical process that moves air into and out of the lungs.

2. External respiration/alveolar respiration/: mov't of air between lung and blood.

3. Transportations of respiratory gases: mov't of respiratory gases by blood to the tissues.

4. Internal respiration/cellular respiration/: mov't of air from blood to the tissues.

STRUCTURES OF RESPIRATORY SYSTEM

- Respiratory tract is the anatomical structure through which air moves in and out.

NOSE

- The nose is a specialized organ at the entrance of the respiratory system.

  ✓ It has external portion and an internal portion.

- The external nose is the portion of the nose visible on the face.

  ✓ It consists of a supporting framework of bone and cartilage covered with muscle and skin and lined by

Structure of the RS cont'd…

- The frontal bone, nasal bones, and maxillae form the bony framework of the external nose.

- The cartilaginous frame work of the external nose consists of the septal nasal cartilage, the lateral nasal cartilages and the alar cartilages.

  - ✓ Because it consists of pliable hyaline cartilage, the cartilaginous framework is somewhat flexible.

- The external nose has two openings called the external nares or nostrils, which are guarded by many internal hairs.

  - ✓ Function of these hairs are preventing entry of large

Structure of the RS cont'd…

- The mucous membrane that lines the interior of external nose has pseudostratified ciliated epithelium that is rich in mucus-secreting goblet cells.

  - ✓ It also includes an extensive network of blood vessels.

  - ✓ As air passes over the mucous membrane, heat leaves the blood and warms the air, adjusting the air's temperature to that of the body.

  - ✓ In addition, incoming air is moistened as water evaporates from the mucous lining.

Structure of the RS cont'd…

- ✓ As the cilia of the epithelial lining move, they push a thin layer of mucus and entrapped particles toward the pharynx, at which point it can be swallowed or spit out, thus removing particles from the respiratory tract.

- The internal nose connects to the throat through two openings called the internal nares or choanae.

- ✓ It's lateral walls are formed by the ethmoid, maxillae, lacrimal, palatine, and inferior nasal conchae bones.

- ✓ The ethmoid bone also forms the roof.

Structure of the RS cont'd…

- Ducts from the paranasal sinuses (which drain mucus) and the nasolacrimal ducts (which drain tears) also connect to the internal nose.

- The space inside the internal nose is called the nasal cavity.

- The nasal cavity is a large space in the anterior aspect of the skull that lies inferior to the nasal bone and superior to the oral cavity.

  - ✓ Anteriorly, it merges with the external nose and posteriorly it communicates with the pharynx through internal nares.

Structure of the RS cont'd…

- ✓ When air enters the nostrils, it passes first through the vestibule, which is lined by skin containing coarse hairs that filter out large dust particles.

- ✓ A vertical partition, the nasal septum, divides the nasal vestibule into right and left sides.

- Nasal conchae are the three shelves like projections from each lateral wall side of the nasal cavity.

- ✓ That dividing the cavity into:- the superior, middle, and inferior meatuses.

- They are three nasal conchae

Structure of the RS cont'd…

- The arrangement of conchae and meatuses increases surface area in the internal nose and prevents dehydration by trapping water droplets during exhalation.

- Mucous membrane lines the nasal cavity and the three conchae.

  - ✓ As inhaled air whirls around the conchae and meatuses, it is warmed by blood in the capillaries.

  - ✓ Mucus secreted by the goblet cells moistens the air and traps dust particles.

Structure of the RS cont'd…

- The nasal cavity is divided into inferior respiratory region and a superior olfactory region.

- The respiratory region is lined with pseudostratified ciliated columnar epithelium with numerous goblet cells, which is frequently called the respiratory epithelium.

- The olfactory receptors, supporting cells, and basal cells lie in the respiratory region, which is near the superior nasal conchae and adjacent septum.

  - ✓ These cells make up the olfactory epithelium.
  - ✓ The olfactory nerves pass through the ethmoid bone

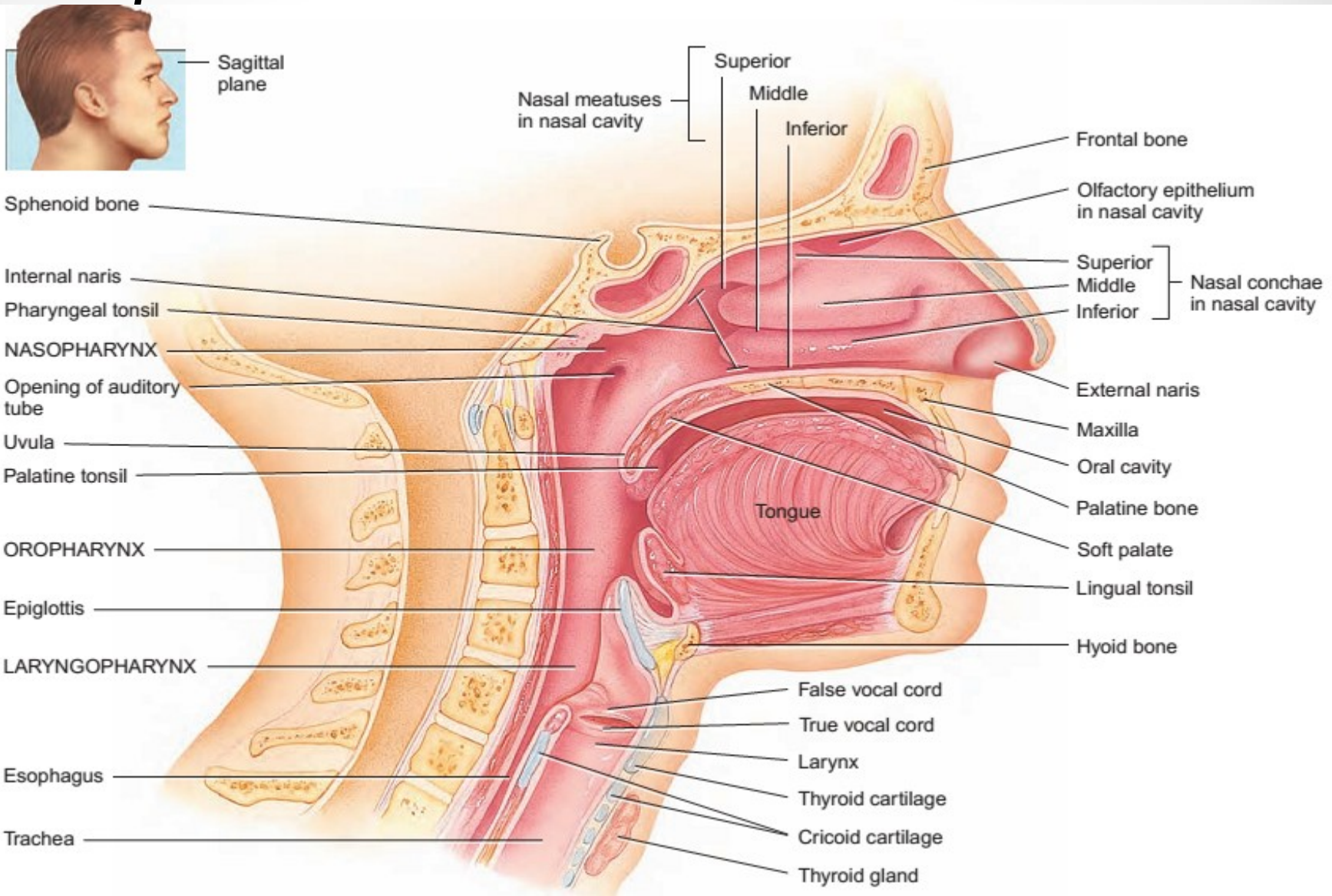
Structure of the RS cont'd…

- The paranasal sinuses are air-filled spaces within the frontal, ethmoid, sphenoid, and maxillary bones of the skull.
    - They are lined with mucous membranes.
- The function of this paranasal sinuses are:-

    i. To reduce the weight of the skull and

    ii. Are resonant chambers that affect the quality of the voice.

Structure of the RS cont'd…



Structure of the RS cont'd…

PHARYNX

- The pharynx, or throat, is a muscular tube posterior to the nasal and oral cavities and anterior to the cervical vertebrae.
- It is a passageway for food moving from the oral cavity to the esophagus and for air passing between nasal cavity and the larynx.
- It also helps produce the sounds of speech.
- It is subdivisions: the nasopharynx, oropharynx, and laryngopharynx.

Structure of the RS cont'd…

- ✓ It is a passageway for air only, but the remainder of the pharynx serves as both an air and food passageway, although not for both at the same time.

- The soft palate is elevated during swallowing to block the nasopharynx and prevent food or saliva from going up rather than down.

  - ✓ The uvula is the part of the soft palate on back of the throat.

- On the posterior wall of the nasopharynx is the adenoid or pharyngeal tonsil, a lymph nodule that

Structure of the RS cont'd…

- ✓ The purpose of the eustachian tubes is to permit air to enter or leave the middle ears, allowing the eardrums to vibrate properly.

- The oropharynx is behind the mouth; its mucosa is stratified squamous epithelium, continuous with that of the oral cavity.

- ✓ On its lateral walls are the palatine tonsils, also lymph nodules.

- ✓ Together with the adenoid and the lingual tonsils on the base of the tongue, they destroy pathogens that penetrate the mucosa.

Structure of the RS cont'd…

LARYNX/VOICE BOX/

- It is a short passageway that connects the laryngopharynx with the trachea.
  - ✓ It lies in the midline of the neck anterior to the esophagus.
- It is composed of a framework of muscles and cartilages bound by elastic tissue.
- The wall of the larynx is composed of nine pieces of cartilage.
  - ✓ Three occur singly (thyroid cartilage, epiglottis, and

Structure of the RS cont'd…

- The cavity of the larynx is the space that extends from the entrance into the larynx down to the inferior border of the cricoid cartilage.
- The epiglottis is a large, leaf shaped piece of elastic cartilage that is covered with epithelium.
- The "stem" of the epiglottis is the tapered inferior portion that is attached to the anterior rim of the thyroid cartilage and hyoid bone.
- The broad superior "leaf " portion of the epiglottis is unattached and is free to move up and down like a trap door.

Structure of the RS cont'd…

- ✓ Elevation of the pharynx widens it to receive food or drink.
- ✓ Elevation of the larynx causes the epiglottis to move down and form a lid over the glottis, closing it off.

- The closing of the larynx in this way during swallowing routes liquids and foods into the esophagus and keeps them out of the larynx and airways.
- When small particles of dust, smoke, food, or liquids pass into the larynx, a cough reflex occurs, usually expelling the material.

Structure of the RS cont'd…

- The thyroid cartilage (Adam's apple) consists of two fused plates of hyaline cartilage that give it a triangular shape.
  - ✓ The thyroid cartilage is the largest cartilage of the larynx.
  - ✓ It is present in both males and females but is usually larger in males due to the influence of male sex hormones on its growth during puberty.
- The cricoid cartilage is a ring of hyaline cartilage that forms the inferior wall of the larynx.

Structure of the RS cont'd…

- The lining of the larynx superior to the vocal folds is nonkeratinized stratified squamous epithelium.

- The lining of the larynx inferior to the vocal folds is pseudostratified ciliated columnar epithelium consisting of ciliated columnar cells, goblet cells, and basal cells.

  - ✓ The mucus produced by the goblet cells helps trap dust not removed in the upper passages.

  - ✓ The cilia in the upper respiratory tract move mucus and trapped particles down toward the pharynx; the

Structure of the RS cont'd…

- The larynx is also called the voice box.

  - ✓ The mucous membrane of larynx forms two pairs of vocal cords:

1. A superior pair called the ventricular folds (false vocal cords).

   - The space between the ventricular folds is known as the rima vestibuli.

   - They are called false vocal cords because they do not produce sounds.

- The false vocal cords do have other important

Structure of the RS cont'd…

ii. When the ventricular folds are brought together, they function in holding the breath against pressure in the thoracic cavity.

2. An inferior pair called the vocal folds (true vocal cords).

   ✓ The portion of the cavity of the larynx above the true vocal cords is called the vestibule of the larynx.

- The vocal folds are the principal structures of voice production.

- Deep to the mucous membrane of the vocal folds are bands of elastic ligaments stretched between the rigid

Structure of the RS cont'd…

- When the muscles contract they move the cartilages, which pulls the elastic ligaments tight, and this stretches the vocal folds out into the airways so that the rima glottidis is narrowed.

- Contracting and relaxing the muscles varies the tension in the vocal folds, much like loosening or tightening a guitar string.

- Pitch is controlled by the tension on the vocal folds.

- If they are pulled taut by the muscles, they vibrate more rapidly, and a higher pitch results.

- Decreasing the muscular tension on the vocal folds

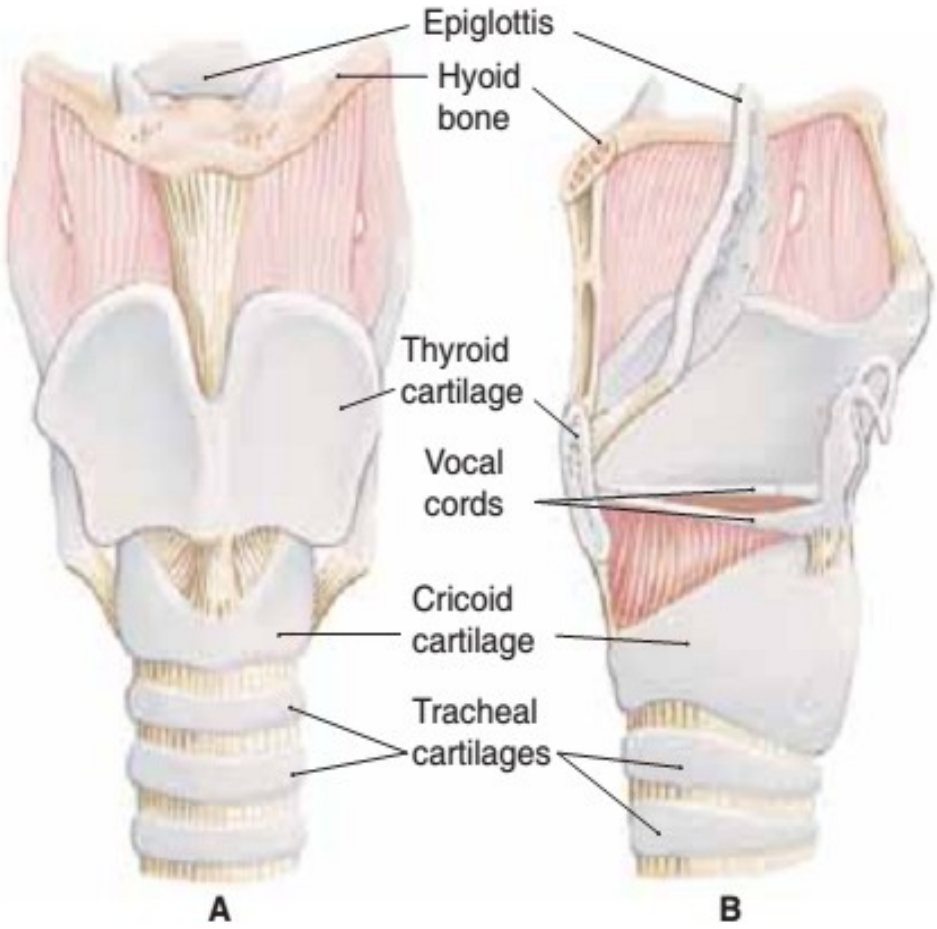
Structure of the RS cont'd…

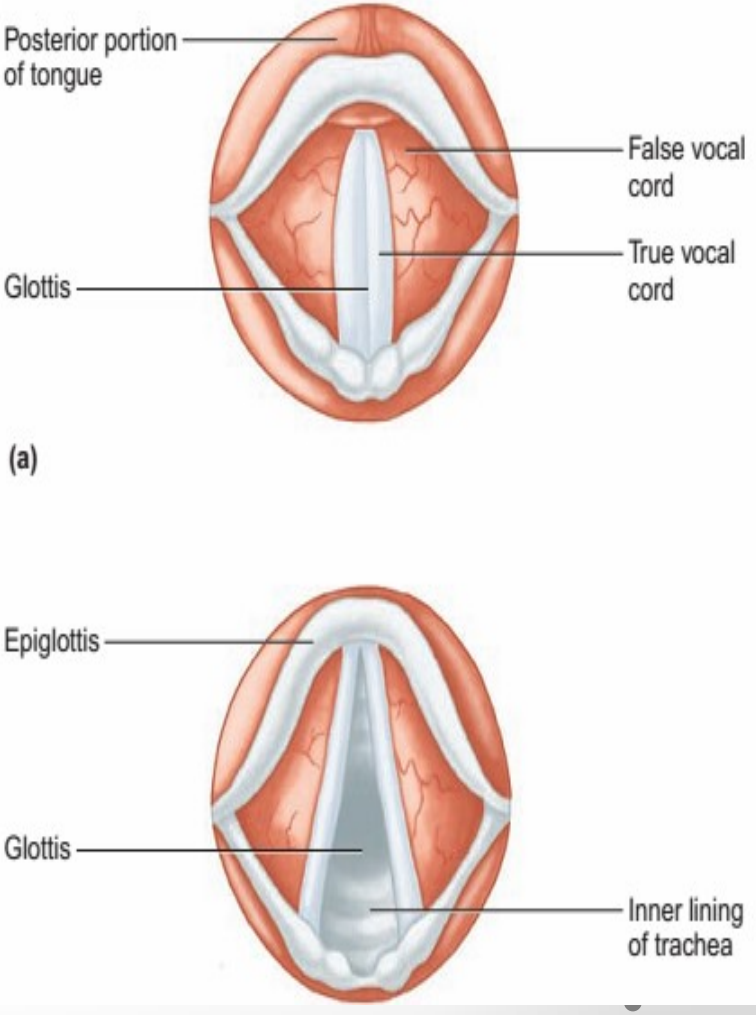
- Due to the influence of male sex hormones, vocal folds are usually thicker and longer in males than in females.
  - ✓ Therefore they vibrate more slowly.
  - ✓ This is why a man's voice generally has a lower range of pitch than that of a woman.
- Sound originates from the vibration of the vocal folds, but other structures are necessary for converting the sound into recognizable speech.
  - ✓ The pharynx, mouth, nasal cavity, and paranasal

Structure of the RS cont'd…

- The vowel sounds are produceed by constricting and relaxing the muscles in the wall of the pharynx.
- Muscles of the face, tongue, and lips help us enunciate words.
- Whispering is accomplished by closing all but the posterior portion of the rima glottidis.
- Because the vocal folds do not vibrate during whispering, there is no pitch to this form of speech.
- As the size of the oral cavity changes, its resonance qualities change, which imparts a vowel-like pitch to

Structure of the RS cont'd…





Structure of the RS cont'd…

TRACHEA

- The trachea or windpipe, is a flexible cylindrical tube about 10 to 13 cm in length with 2.5cm diameter.

- Its wall contains 16 to 20 C-shaped pieces of hyaline cartilage, one above the other to keep the trachea open.

    - ✓ The open ends of these incomplete rings are directed posteriorly, and smooth muscle and connective tissues fill the gaps between the ends.

Structure of the RS cont'd…

- A ciliated mucous membrane with many goblet cells lines the trachea's inner wall.
  - ✓ This membrane filters incoming air and moves entrapped particles upward into the pharynx, where the mucus can be swallowed.
- It extends downward anterior to the esophagus and into the thoracic cavity, where it splits into right and left bronchi.
- Trachea and bronchi are together called tracheobronchial tree.

Structure of the RS cont'd…

BRONCHIAL TREE

- The bronchial tree consists of branched airways leading from the trachea to the microscopic air sacs in the lungs.

- Components of tracheobronchial tree are:

  i. ***Trachea*** bifurcates into two main or primary bronchi called ***right and left bronchi*** at the level of the fifth thoracic vertebra.

  - ✓ Their structure is just like that of the trachea, with C-shaped cartilages and ciliated epithelium.

Structure of the RS cont'd…

ii. Each primary bronchus enters the lungs and divides into ***secondary (lobar) bronchi*** (three right and two left).

iii. Secondary bronchi divide into ***tertiary (segmental) bronchi***.

- ✓ In right lung, there are 10 tertiary bronchi and in left lung, there are eight tertiary bronchi.

iv. Tertiary bronchi divide several times with reduction in length and diameter into many generations of ***bronchioles.***

Structure of the RS cont'd…

iv. Terminal bronchiole continues or divides into ***respiratory bronchioles***, which have a diameter of 0.5 mm.

RESPIRATORY UNIT

- Parenchyma of lungs is formed by respiratory unit that forms the **terminal portion** of respiratory tract.

  ✓ Respiratory unit is defined as the structural and functional unit of lung.

    - Exchange of gases occurs only in this part of the respiratory tract.

Structure of the RS cont'd…

- Each respiratory bronchiole divides into alveolar ducts.
- Each alveolar duct enters an enlarged structure called the alveolar sac.
- Space inside the alveolar sac is called antrum.
- Alveolar sac consists of a cluster of alveoli.
- Few alveoli are present in the wall of alveolar duct also.
- Thus, respiratory unit includes: respiratory bronchioles, alveolar ducts, alveolar sacs, antrum and alveoli.

Structure of the RS cont'd…

- The lungs there are about 300 million tiny alveoli.
- Each alveolus is like a pouch with the diameter of about 0.2 to 0.5 mm.
- Alveoli are polyhedral in shape.
- They are found in:-

a. In clusters: usually occur at the ends of respiratory bronchioles, like the units of a honeycomb.

   - ✓ Air within one member of a cluster can enter other members through tiny pores.

Structure of the RS cont'd…

b. Individual alveoli: occur as separate outpouchings along the length of respiratory bronchioles.

- Alveoli are area of gas exchange:-

1. Their enormous number provides a large surface area (60 to 80 square meters) for diffusion of gases.

2. They are only one cell-layer thick:- this further increase diffusion rate.

✓ There are two types of alveolar cells, designated
- type I alveolar cells and type II alveolar cells.

Structure of the RS cont'd…

3. The alveolar wall isn't fragile but is strong enough to withstand high stress during heavy exercise and high lung inflation.

   - ✓ The great tensile strength of the alveolar wall is provided by the fused basement membranes (composed of type IV collagen proteins) of the blood capillaries and the alveolar walls.

- Alveolar epithelium consists of alveolar cells or pneumocytes, which are of two types namely:

1) Type I alveolar cells are the squamous epithelial cells forming about 95% to 97% of the total number of cells.

Structure of the RS cont'd…

- These cells are accordingly very thin.

2) Type II alveolar cells are cuboidal in nature and form about 3 - 5% of alveolar cells.

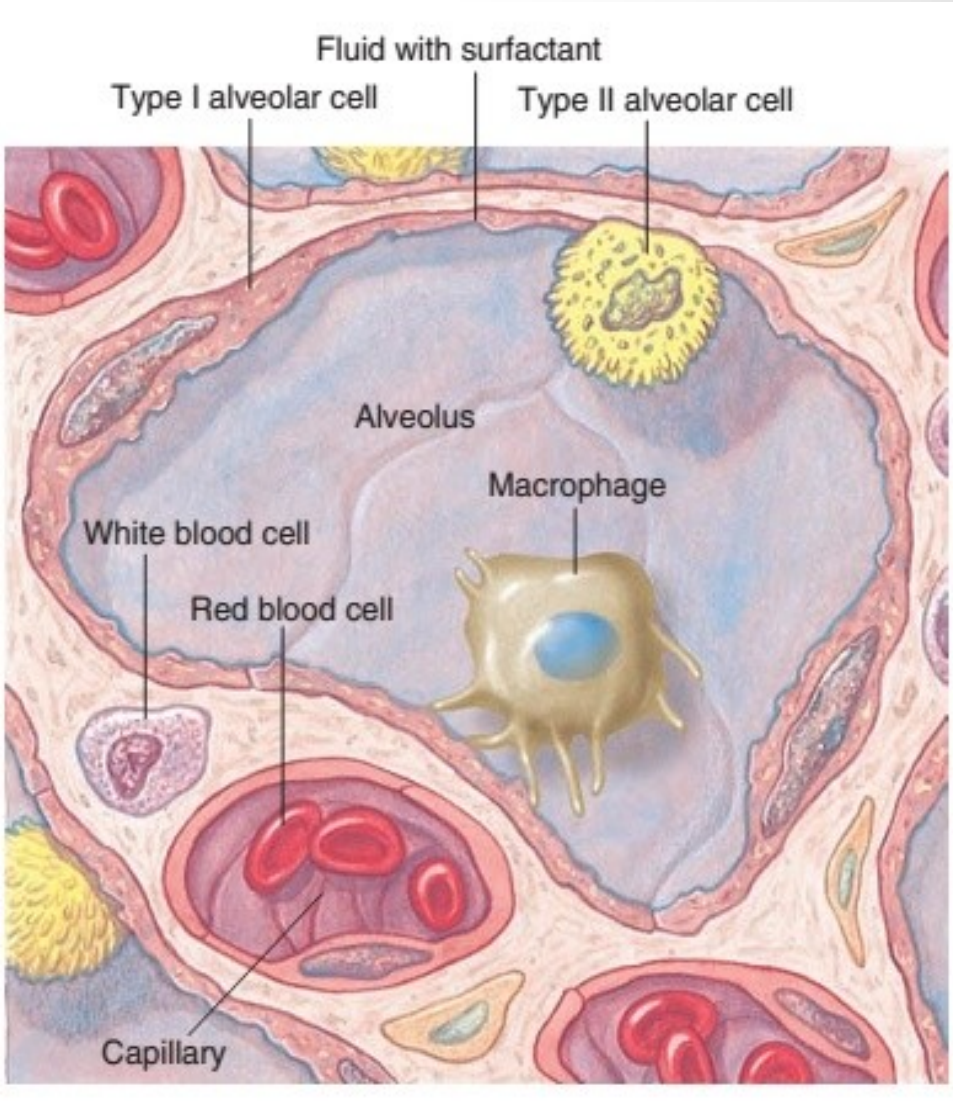
- ✓ These cells are also called granular pneumocytes.
- ✓ Type II alveolar cells secrete alveolar fluid and surfactant.
  - Surfactant reduce surface tension
- ✓ Type II alveolar cells also reabsorb Na^+ and H_2O:-

Structure of the RS cont'd…

- As the branching becomes more extensive in the bronchial tree, several structural changes may be noted.

1. The mucous membrane in the bronchial tree changes from:-

   ✓ Pseudostratified
   - ciliated columnar



Structure of the RS cont'd…

- ✓ Ciliated simple columnar epithelium with some goblet cells in larger bronchioles, to
- ✓ Mostly ciliated simple cuboidal epithelium with no goblet cells in smaller bronchioles, to
- ✓ Mostly nonciliated simple cuboidal epithelium in terminal bronchioles.

- Recall that ciliated epithelium of the respiratory membrane removes inhaled particles in two ways.
  - ✓ Mucus produced by goblet cells traps the particles, and the cilia move the mucus and trapped particles

Structure of the RS cont'd…

- In regions where nonciliated simple cuboidal epithelium is present, inhaled particles are removed by macrophages.

2. Plates of cartilage gradually replace the incomplete rings of cartilage in primary bronchi and finally disappear in the distal bronchioles.

3. As the amount of cartilage decreases, the amount of smooth muscle increases.

- Smooth muscle encircles the lumen in spiral bands and helps maintain patency.

Structure of the RS cont'd…

- This is what happens during an asthma attack, which can be a life-threatening situation.

4. Resistance to airflow in the bronchial tree.

- Under *normal respiratory conditions:*

  - Air flows through the respiratory passageways so easily that less than 1 centimeter of water pressure gradient from the alveoli to the atmosphere is sufficient to cause enough airflow for quiet breathing.

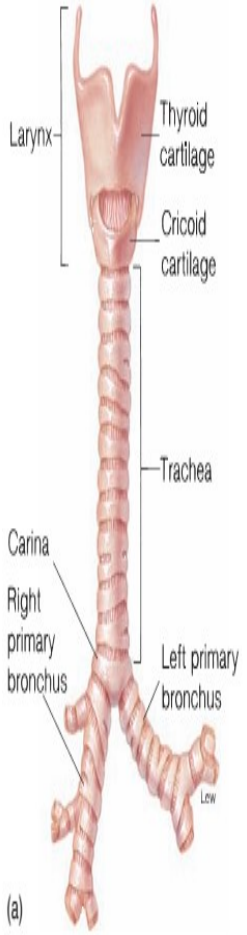
  - Greatest amount of resistance to airflow occurs in

Structure of the RS cont'd…

- Under disease conditions the smaller bronchioles often play a far greater role in determining airflow resistance because of their small size they easily occluded by:

    i. Muscle contraction in their walls,

    ii. Edema occurring in the walls, or





NERVOUS AND LOCAL CONTROL OF THE BRONCHIOLAR MUSCULATURE

- Sympathetic nerve fibers:
  - ✓ Control of the bronchioles is relatively weak because few of these fibers penetrate to the central portions of the lung.
  - ✓ But bronchial tree is very much exposed to *norepinephrine* and *epinephrine* released into the blood by sympathetic stimulation of the adrenal gland medullae; both causes dilation of bronchial trees (β_2 adrenergic receptors).
- Parasympathetic nerve fibers (vagus nerves):

Control of bronchial musculature cont'd…

Local secretory factors:

- Several substances formed in the lungs are often quite active in causing bronchiolar constriction.
- Most important of these are *histamine* and *slow reactive substance of anaphylaxis.*
- These are released in the lung tissues by *mast cells* during allergic reactions.
- They play key roles in causing the airway obstruction that occurs in allergic asthma.

Structure of the RS cont'd…

LUNGS AND PLEURAL MEMBRANES

- The lungs are soft, spongy, cone-shaped organs in the thoracic cavity.
  - ✓ They are encircled and protected by the thoracic cage; the apex (superior tip) is at the level of the clavicle.
  - ✓ The base of each lung rests on the diaphragm below.
- The mediastinum separates the right and left lungs medially.

Structure of the RS cont'd…

- Each lung occupies most of the thoracic space on its side.
- On the medial surface of each lung is an indentation called the hilus.
  - ✓ It is the entry and exit of primary bronchus, blood vessels, connective tissues, lymphatic vessels, and nerves.
- The double layer pleural membranes are the serous membranes of the thoracic cavity that cover the lung.

Structure of the RS cont'd…

a. The visceral pleura: is the inner membrane that firmly attaches to each lung surface and folds back to become the parietal pleura.

b. The parietal pleura: is the outer membrane that forms part of the mediastinum and lines the inner wall of the thoracic cavity.

- There is a potential space between them which is called the pleural cavity.

- It has a thin film of serous fluid:-

A. It lubricates adjacent pleural surfaces, reducing

Structure of the RS cont'd…

- Structurally, the structure of the respiratory system can be divided generally into two groups, or tracts.

  i. Upper respiratory tract:- include the nose, nasal cavity, paranasal sinuses, and pharynx.

  ii. Lower respiratory tract:- include the larynx, trachea, bronchial tree, and alveoli.

- The air passages of the RS are also divided into two functional zones.

  1. The conducting zone:- includes all of the

Structure of the RS cont'd…

- ✓ The nose, nasal cavity, paranasal sinus, pharynx, larynx, trachea, primary bronchi, and all successive branching's of the bronchioles up to and including the terminal bronchioles.

- Between the trachea and the alveolar sacs, the airways divide 23 times.

- ✓ The first 16 generations of passages form the conducting zone of the airways that transports gas from and to the exterior.

- The functions of conducting zones are:-

1. Conduction of air into the respiratory zone

Structure of the RS cont'd…

3. Maintaining body temperature

- ✓ When the inspired air reaches the respiratory zone it is at a temperature of 37°C, and it is saturated with water vapor as it flows over the warm, wet mucous membranes.

- ✓ This ensures that:-

  - o A constant internal body temperature will be maintained and

  - o The lung tissue will be protected from desiccation.

Structure of the RS cont'd…

- There are about 300 cilia per epithelial cells that lines conducting zone to produce a mucus, which serves to trap small particles in the inspired air and thereby performs a filtration function.

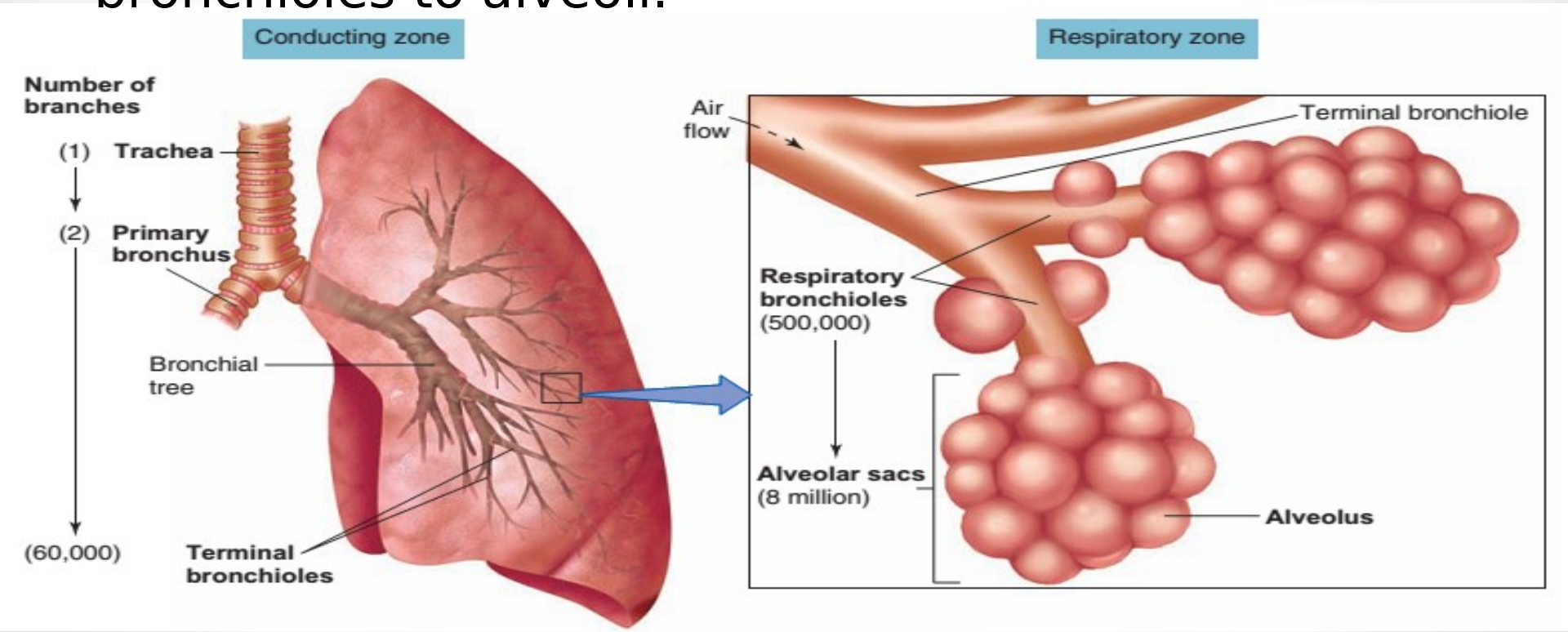
  - ✓ This mucus is moved along at a rate of 1 to 2 cm/min by cilia.

- They beat in a coordinated fashion to move mucus toward the pharynx, where it can either be swallowed or expectorated.

  - ✓ As a result of this filtration function, particles larger than about 6µm do not normally enter the respiratory zone of the lungs.

Structure of the RS cont'd…

2. The respiratory zone is the region where gas exchange occurs, and it therefore includes the respiratory bronchioles to alveoli.



NON-RESPIRATORY FUNCTIONS OF RESPIRATORY SYSTEM

- Provides a route for water and heat elimination
- Olfaction
- Maintenance of acid base balance
- Vocalization (phonation)
- Defense against foreign materials
- Conversion of angiotensin-I to angiotensin-II by the action of ACE
- Enhances venous return

MECHANICS OF BREATHING

- It is the action of breathing in and out is due to changes of pressure within the thorax and the lungs, in comparison with the outside (atmosphere).

- It is as a result of

1. ***A flexible thorax*** that can function as a bellows during the ventilation cycle.

   ✓ The structure of the rib cage and associated cartilages provides continuous elastic tension.

- Between the rib cage there are two layers of intercostal muscles:-

Mechanics of breathing cont'd…

- Between the costal cartilages, however, there is only one muscle layer, and its fibers are oriented similar to those of the internal intercostals.

  - ✓ These muscles are therefore called the interchondral part of the internal intercostals or the parasternal intercostals.

2. ***The elasticity of the lungs:*** this elastic recoil is greatly aided by the elasticity of the lungs.

- Pulmonary ventilation (breathing) consists of two phases:-

- Inspiration (inhalation) and expiration (exhalation).

Pleural Pressure And Alveolar Pressure Change During Respiration

1. *Pleural pressure (intrapleural pressure):*

- Is the pressure in the thin space between the lung visceral and the chest wall pleura.

- It is a slightly *negative* pressure (is about -5 mmHg)

  - ✓ During quite inspiration, it is more negative (about -8 mmHg).

  - ✓ During quite expiration, it is less negative (about -2 mmHg).

Mechanics of breathing cont'd…

2. Alveolar pressure (intrapulmonary pressure):

- It is the pressure of the air inside the lung alveoli.
- When there is no air flow (glottis is open) into or out of the lungs, the pressures in side the alveoli, are equal to atmospheric pressure.
  - ✓ It is considered to be zero reference pressure in the airways.
  - ✓ During quite inspiration, it decreases by about -1 mmHg.

Mechanics of breathing cont'd…

3. Transpulmonary pressure:

- It is the difference between the alveolar pressure and the pleural pressure.

- It is a measure of the elastic forces in the lungs that tend to collapse the lungs at each instant of respiration.

  - ✓ Therefore it is called the *recoil pressure*

INSPIRATION

Inspiratory muscle

- There are two types of inspiratory muscles

1. Principal inspiratory muscle.

i. Diaphragm

- It is a dome-shaped muscle that separates abdominal cavity from thoracic cavity.

- It is innervated by phrenic nerve.

Inspiration cont'd…

- The diaphragm has three parts:

  A. The costal portion:- made up of muscle fibers that are attached to the ribs around the bottom of the thoracic cage

  B. The crural portion:- made up of fibers that are attached to the ligaments along the vertebrae; and

  C. The central tendon, into which the costal and the crural fibers insert.

- Movement of the diaphragm accounts for 75% of the

Inspiration cont'd…

- Contraction of diaphragm → movement of diaphragm downward → ↑ vertical dimension of thoracic cavity → lowering of air pressure in lungs → movement of air into lungs.
- Lungs are stretched & ↑ intrapulmonary volume
- Intrapulmonary pressure drops below atmospheric pressure (-1 mm Hg).
- Intrapleural pressure drops below atmospheric pressure (-8 mm Hg).
- Air flows into the lungs until pressures equalizes

Inspiration cont'd…

ii. Parasternal and external intercostals

- Motor impulses from the medulla travel along the intercostal nerves them.
- They cause inspiration by raising the ribs when they contract.
- This pushes the sternum outward and increases the anteroposterior diameter of the chest.
- The transverse diameter also increases, but to a lesser degree.

Inspiration cont'd…

- Contraction of external intercostal and parasternal muscles → elevation of ribs & sternum → ↑AP dimension of thoracic cavity → lowers air pressure in lungs → moving of air into lungs.

2. Accessory inspiratory muscles

- They are involved in forced (deep) inspiration.
- These are:- the scalenes, the pectoralis minor, the sternocleidomastoid and serratus anterior muscles.
- Contraction of these muscles elevates the ribs in an AP

EXPIRATION

1. Quiet expiration is a passive process.

- Inspiratory muscles relax & the rib cage descends due to gravity ↓ thoracic cavity volume.

- Elastic lungs recoil passively and ↓ intrapulmonary volume.

- Intrapulmonary pressure rises above atmospheric pressure (+1 mm Hg)

- Gases flow out of the lungs down the pressure gradient

Expiration cont'd…

2. Muscle of forced expiration,

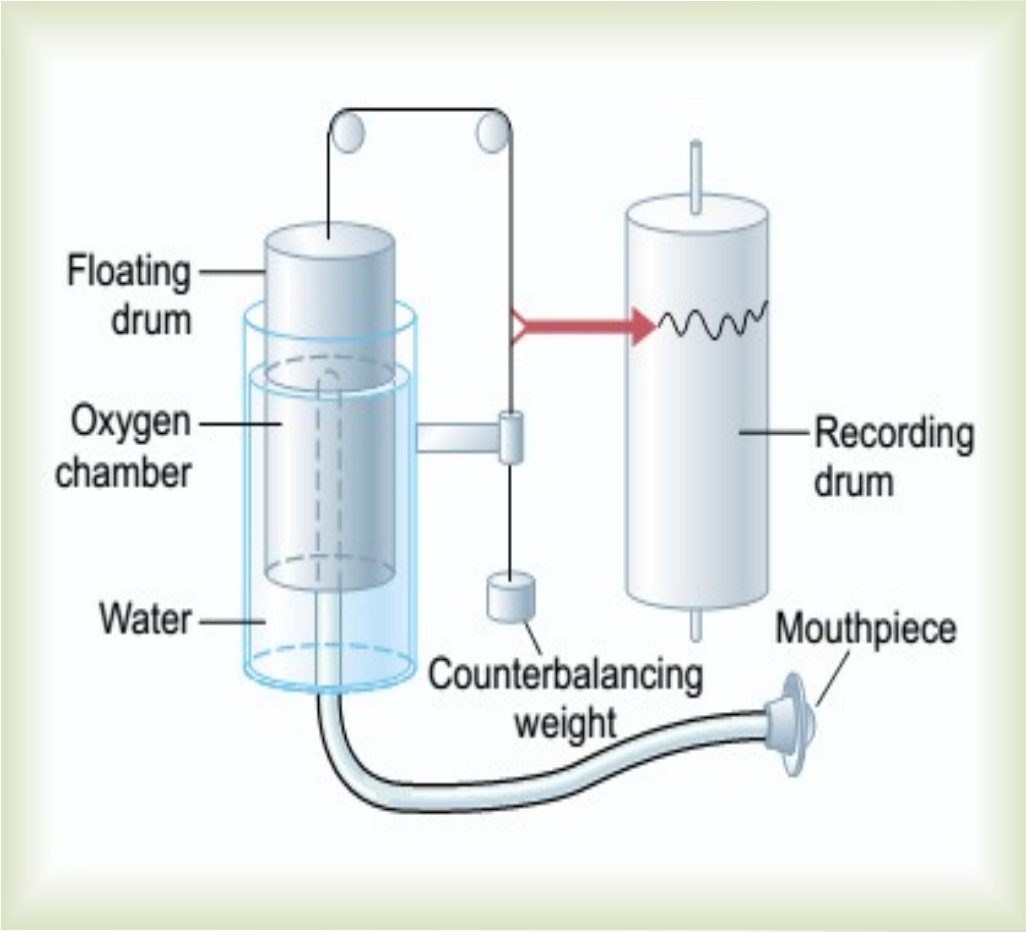
a. The internal intercostal muscles:- contract and depress the rib cage.

b. The abdominal muscles:- also aid expiration because, when they contract, they force abdominal organs up against the diaphragm and further decrease the volume of the thorax.

- ✓ By this means the intrapulmonary pressure can raise 20 or 30 mmHg above the atmospheric pressure.

PULMONARY FUNCTION TESTS

- Pulmonary function may be assessed clinically by means of a technique known as spirometry.
- By spirometry, four lung volumes and four lung capacities are measured, which are the average for a young adult man.



PULMONARY VOLUMES

1. The tidal volume: - is the volume of air inspired or expired with each normal breath; (500 ml in the adult male).

2. The inspiratory reserve volume:- is the extra volume of air that can be inspired over and above the normal tidal volume when the person inspires with full force; (3000 ml).

3. The expiratory reserve volume: - is the maximum extra volume of air that can be expired by forceful expiration after the end of a normal tidal expiration; (1100 ml).

PULMONARY CAPACITIES

1. The inspiratory capacity: - equals TV + IRV = 3500 ml.

- This is the amount of air a person can breathe in, beginning at the normal expiratory level and distending the lungs to the maximum amount.

2. The functional residual capacity: - equals ERV + RV.

- This is the amount of air that remains in the lungs at the end of normal expiration (about 2300 milliliters).

Pulmonary capacities cont'd…

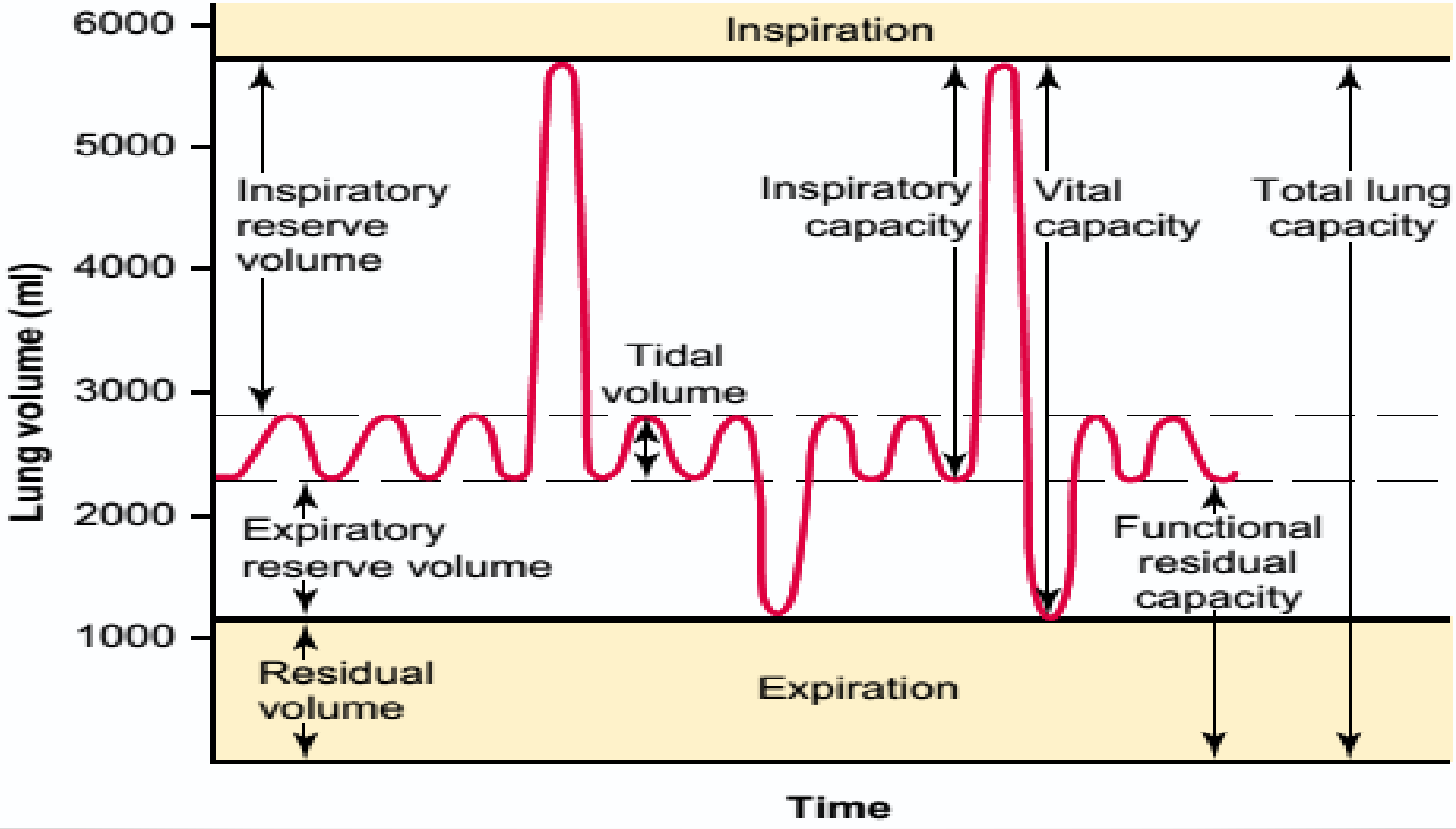
3. The vital capacity: - equals IRV + TV + ERV = 4600ml.

- This is the maximum amount of air a person can expel from the lungs after first filling the lungs to their maximum extent and then expiring to the maximum extent.

4. The total lung capacity: - is the maximum volume to which the lungs can be expanded with the greatest possible effort (about 5800 milliliters)

- It is equal to the vital capacity plus the residual volume.

Pulmonary capacities cont'd…



Minute Ventilation (Minute Respiratory Volume)

- It is the total amount of new air moved into the respiratory passages each minute.
- It is equal to the tidal volume times the respiratory rate per minute.
- Breathing frequency measured by observing chest movement and stetography.
  - ✓ = 12 breaths /min in adults
  - ✓ = 14-16 breaths /min in newborns
- Normal tidal volume is about 500 milliliters (adult)

Alveolar ventilation

- It is the rate at which new air reaches the gas exchange areas of the lungs (alveoli, alveolar sacs, alveolar ducts, and respiratory bronchioles).

- Some of the air a person breathes never reaches the gas exchange areas but simply fills respiratory passages where gas exchange does not occur (the conducting zone), such as the nose, pharynx, and trachea.

  - ✓ Air in this space (conducting zone) is called the *anatomic dead space.*

- The normal anatomical dead space air in a young adult man is about 150 milliliters.

AV cont'd…

- ✓ Therefore, from a functional point of view, these alveoli must also be considered dead space (forms alveolar dead space).

- When the alveolar dead space is included in the total measurement of dead space, this is called the physiologic dead space.

Alveolar ventilation per minute

- It is the total volume of new air entering the alveoli and adjacent gas exchange areas each minute.

$$V_A = \text{Freq.} \times (V_T - V_D)$$

Where;

- V_A = the volume of alveolar ventilation per minute
- Freq = the frequency of breathing per minute
- V_T = the tidal volume
- V_D = the physiologic dead space volume.

AV/min cont'd…

- In an adult male;
  - ✓ VA = (500ml – 150ml)×12 = 4200 ml/min
- Alveolar ventilation can be increased by raising either tidal volume or respiratory frequency (or both).
- Increasing tidal volume is often more effective because this reduces the proportion of each breath occupied by the anatomic dead space.

RESPIRATORY MEMBRANE

- Respiratory membrane (air blood barrier) is a membranous structure through which exchange of respiratory gases takes place.
- It is formed by epithelium of respiratory unit and endothelium of pulmonary capillary.
- Epithelium of respiratory unit is a very thin layer.
  - ✓ Since, the capillaries are in close contact with this membrane, alveolar air is in close proximity to capillary blood.

Respiratory membrane cont'd…

- Respiratory membrane is formed by different layers of structures belonging to the alveoli and capillaries.

- The following are different layers of the respiratory membrane:-

    1. A layer of fluid lining the alveolus and containing surfactant that reduces the surface tension of the alveolar fluid

    2. The alveolar epithelium composed of thin epithelial cells

    3. An epithelial basement membrane

Respiratory membrane cont'd…

5. A capillary basement membrane that in many places fuses with the alveolar epithelial basement membrane.

6. The capillary endothelial membrane

•Despite the large number of layers, the overall thickness of the respiratory membrane in some areas is as little as 0.2 micrometer, and it averages about 0.6 micrometer, except where there are cell nuclei.

•There is rapidity of the respiratory exchange of oxygen and carbon dioxide across this respiratory membrane as a result of:

Respiratory membrane cont'd…

i. The total surface area of the respiratory membrane is about 70 square meters in the normal adult human male.

- The total quantity of blood in the capillaries of the lungs at any given instant is 60 to 140 milliliters.

ii. The average diameter of the pulmonary capillaries is only about 5 micrometers.

- The RBC membrane usually touches the capillary wall, so that O_2 and CO_2 need not pass through significant amounts of plasma as they diffuse between the

DIFFUSING CAPACITY

- Diffusing capacity is defined as the volume of gas that diffuses through the respiratory membrane each minute for a pressure gradient of 1 mm Hg.

- Diffusing capacity for oxygen is 21 mL/minute/1 mm Hg.

- Diffusing capacity for carbon dioxide is 400 mL/minute/1 mm Hg.

  ✓ Thus, the diffusing capacity for carbon dioxide is about 20 times more than that of oxygen.

Factors Affecting Diffusing Capacity

1. *Pressure gradient*

   - ✓ Diffusing capacity is directly proportional to pressure gradient.
   - ✓ Pressure gradient is the difference between the partial pressure of a gas in alveoli and pulmonary capillary blood.
   - ✓ It is the major factor, which affects the diffusing capacity.

2. *Solubility of gas in fluid medium*

Factors cont'd…

- ✓ If the solubility of a gas is more in the fluid medium, a large number of molecules dissolve in it and diffuse easily.

3. *Total surface area of respiratory membrane*

- ✓ Diffusing capacity is directly proportional to surface area of respiratory membrane.
- ✓ Surface area of respiratory membrane in each lung is about 70 sq m.
- ✓ If the total surface area of respiratory membrane decreases, the diffusing capacity for the gases is

Factors cont'd…

- ✓ Diffusing capacity is decreased in emphysema in which many of the alveoli are collapsed because of heavy smoking or oxidant gases.

4. *Molecular weight of the gas*

- ✓ Diffusing capacity is inversely proportional to molecular weight of the gas.
- ✓ If the molecular weight is more, the density is more and the rate of diffusion is less.

5. *Thickness of respiratory membrane*

Factors cont'd…

- ✓ Diffusion is inversely proportional to the thickness of respiratory membrane.
- ✓ More the thickness of respiratory membrane less is the diffusion.
- ✓ It is because the distance through which the diffusion takes place is long.
- ✓ In conditions like fibrosis and edema, the diffusion rate is reduced, because the thickness of respiratory membrane is increased.

OXYGEN TRANSPORT

- Partial pressure of oxygen in the atmospheric air is 159 mm Hg and in the alveoli, it is 104 mm Hg.

- Because of the pressure gradient of 55 mm Hg, oxygen easily enters from atmospheric air into the alveoli.

- O_2 delivery to a particular tissue depends on the amount of O_2 entering the lungs, the adequacy of pulmonary gas exchange, the blood flow to the tissue, and the capacity of the blood to carry O_2.

  - ✓ The amount of O_2 in the blood is determined by the amount of dissolved O_2, the amount of hemoglobin

O_2 transportation cont'd…

- When blood passes through pulmonary capillary, RBC is exposed to oxygen only for 0.75 second at rest and only for 0.25 second during severe exercise.
  - ✓ So, diffusion of oxygen must be quicker and effective.
  - ✓ Fortunately, this is possible because of pressure gradient.
- Partial pressure of oxygen in the pulmonary capillary is 40 mm Hg and in the alveoli, it is 104 mm Hg.

O_2 transportation cont'd…

- Partial pressure of oxygen in venous end of pulmonary capillary is 104 mm Hg.
  - ✓ However, partial pressure of oxygen in the arterial end of systemic capillary is only 95 mm Hg.
    - o It may be because of physiological shunt in lungs.
    - o Due to venous admixture in the shunt, 2% of blood reaches the heart without being oxygenated.
- Average oxygen tension in the tissues is 40 mm Hg.

O_2 transportation cont'd…

- ✓ Thus, a pressure gradient of about 55 mm Hg exists between capillary blood and the tissues so that oxygen can easily diffuse into the tissues.

- Oxygen content in arterial blood is 19 mL% and in the venous blood, it is 14 mL%.

- ✓ Thus, the diffusion of oxygen from blood to tissues is 5 mL/100 mL of blood.

Gas	Arterial end of pulmonary capillary	Alveoli	Venous end of pulmonary capillary	Arterial end of systemic capillary	Tissue	Venous end of systemic capillary
pO_2 (mm Hg)	40	104	104	95	40	40
Oxygen content (mL%)	14	–	19	19	–	14
pCO_2 (mm Hg)	46	40	40	40	46	46
Carbon dioxide content (mL%)	52	–	48	48	–	52

REACTION OF HEMOGLOBIN AND OXYGEN

- Oxygen is transported in two forms:
  - ✓ Being bound to hemoglobin (chemical form) - 97%
  - ✓ Being dissolved in plasma (physical form) - 3%
- Oxygen dissolves in water of plasma and is transported in this physical form.
  - ✓ Amount of oxygen transported in this way is very negligible.
    - o It is only 0.3 mL/100 mL of plasma.

Reaction of Hgb and O_2 cont'd…

- It is because of poor solubility of oxygen in water content of plasma.
- Still, transport of oxygen in this form becomes important during the conditions like muscular exercise to meet the excess demand of oxygen by the tissues.
- Oxygen also combines with hemoglobin in blood and is transported as oxyhemoglobin.
  - ✓ The dynamics of the reaction of hemoglobin with O_2 make it a particularly suitable O_2 carrier.
  - ✓ The iron stays in the ferrous state, so that the

Reaction of Hgb and O_2 cont'd…

- Hemoglobin accepts oxygen readily whenever the partial pressure of oxygen in the blood is more.
- Hemoglobin gives out oxygen whenever the partial pressure of oxygen in the blood is less.
- Oxygen combines with the iron in heme part of hemoglobin.
- Each molecule of hemoglobin contains 4 atoms of iron.
- Iron of the hemoglobin is present in ferrous form.
- Each iron atom combines with one molecule of oxygen.

Reaction of Hgb and O_2 cont'd…

- After combination, iron remains in ferrous form only.
  - ✓ That is why the combination of oxygen with hemoglobin is called oxygenation and not oxidation.
- Because it contains four deoxyhemoglobin (Hb) units, the hemoglobin molecule can also be represented as Hb_4, and it actually reacts with four molecules of O_2 to

$$Hb_4 + O_2 \rightleftarrows Hb_4O_2$$
$$Hb_4O_2 + O_2 \rightleftarrows Hb_4O_4$$
$$Hb_4O_4 + O_2 \rightleftarrows Hb_4O_6$$
$$Hb_4O_6 + O_2 \rightleftarrows Hb_4O_8$$

- The reaction is rapid, requiring less than 0.01 s.

Reaction of Hgb and O_2 cont'd…

- The quaternary structure of hemoglobin determines its affinity for O_2.
- In deoxyhemoglobin, the globin units are tightly bound in a tense (T) configuration, which reduces the affinity of the molecule for O_2.
- When O_2 is first bound, the bonds holding the globin units are released, producing a relaxed (R) configuration, which exposes more O_2 binding sites.
- When fully saturated, each gram of normal hemoglobin contains 1.39 mL of O_2.

Reaction of Hgb and O_2 cont'd…

- The hemoglobin concentration in normal blood is about 15 g/dL (14 g/dL in women and 16 g/dL in men).
  - ✓ Therefore, 1 dL of blood contains 20.1 mL (1.34 mL ×15) of O_2 bound to hemoglobin when the hemoglobin is 100% saturated.
- Because of a slight admixture with venous blood that bypasses the pulmonary capillaries (physiologic shunt), the hemoglobin in systemic arterial blood is only 97% saturated.
  - ✓ The arterial blood therefore contains a total of

Reaction of Hgb and O_2 cont'd…

- In venous blood at rest, the hemoglobin is 75% saturated and the total O_2 content is about 15.2 mL/dL: 0.12 mL in solution and 15.1 mL bound to hemoglobin.
- Thus, at rest the tissues remove about 4.6 mL of O_2 from each deciliter of blood passing through them.
  - ✓ 0.17 mL of this total represents O_2 that was in solution in the blood, and the remainder represents O_2 that was liberated from hemoglobin.
  - ✓ In this way, 250 mL of O_2 per minute is transported

Reaction of Hgb and O_2 cont'd…

	mL/dL of Blood Containing 15 g of Hemoglobin			
	Arterial Blood (Po_2 95 mm Hg; Pco_2 40 mm Hg; Hb 97% Saturated)		Venous Blood (Po_2 40 mm Hg; Pco_2 46 mm Hg; Hb 75% Saturated)	
Gas	Dissolved	Combined	Dissolved	Combined
O_2	0.29	19.5	0.12	15.1
CO_2	2.62	46.4	2.98	49.7
N_2	0.98	0	0.98	0

Oxygen-hemoglobin Dissociation Curve

- Saturation is the state or condition when hemoglobin is unable to hold or carry any more oxygen.
- Saturation of hemoglobin with oxygen depends upon partial pressure of oxygen.
- Oxygen-hemoglobin dissociation curve is the curve that demonstrates the relationship between partial pressure of oxygen and the percentage saturation of hemoglobin with oxygen.
- It explains hemoglobin’s affinity for oxygen.

Reaction of Hgb and O_2 cont'd…

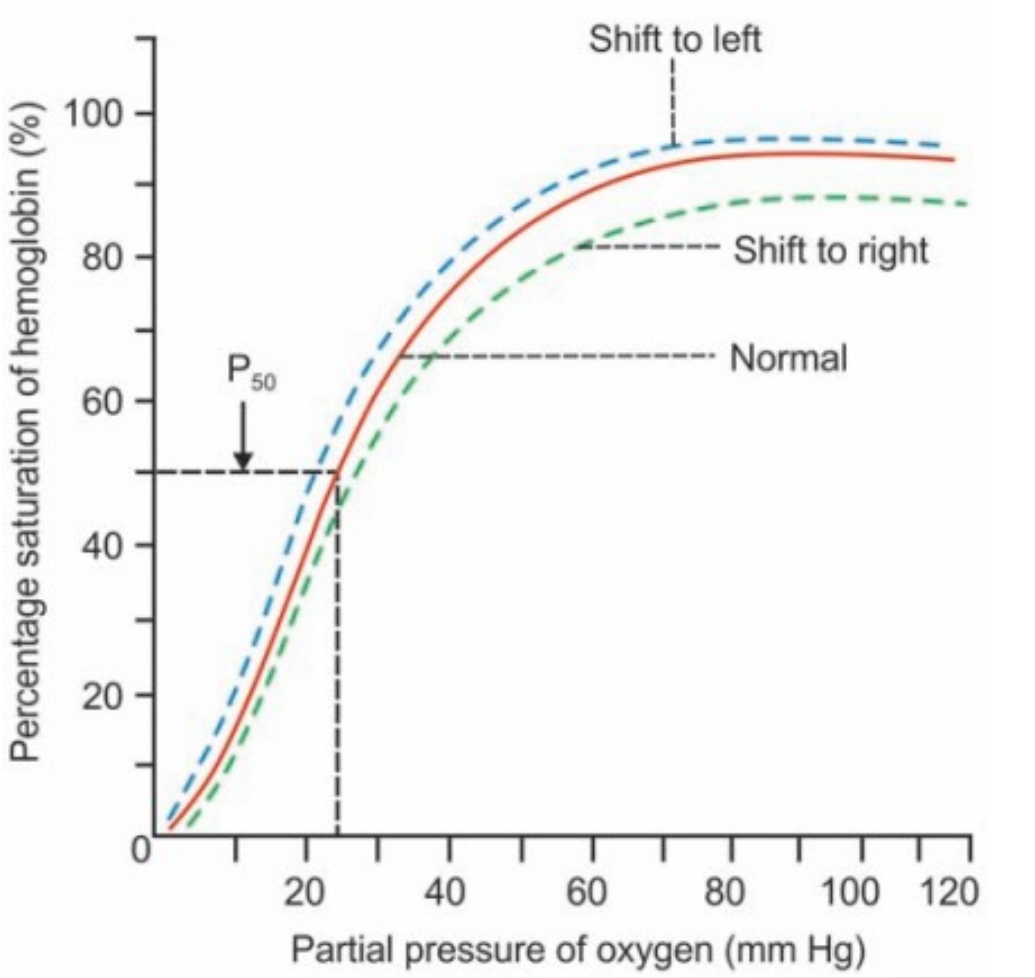
- Saturation of hemoglobin with oxygen depends upon the partial pressure of oxygen.
- When the partial pressure of oxygen is more, hemoglobin accepts oxygen and when the partial pressure of oxygen is less, hemoglobin releases oxygen.
- Under normal conditions, oxygen-hemoglobin dissociation curve is 'S' shaped or sigmoid shaped.
  - ✓ Lower part of the curve indicates dissociation of oxygen from hemoglobin.

Reaction of Hgb and O_2 cont'd…

- P_{50} is the partial pressure of oxygen at which hemoglobin saturation with oxygen is 50%.
- When the partial pressure of oxygen is 25 to 27 mm Hg, the hemoglobin is saturated to about 50%.
  - ✓ That is, the blood contains 50% of oxygen.
- At 40 mm Hg of partial pressure of oxygen, the saturation is 75%.
- It becomes 95% when the partial pressure of oxygen is 100 mm Hg.

Reaction of Hgb and O_2 cont'd…

- Oxygen-hemoglobin dissociation curve is shifted to left or right by various factors:
  - ✓ Shift to left indicates acceptance **(association)** of oxygen by hemoglobin
  - ✓ Shift to right



Factors Affecting The Affinity Of Hemoglobin For Oxygen

- Factors are:- pH, temperature, concentration of 2,3-biphosphoglycerate, H^+ and PCO_2 .
- A rise in temperature, 2,3-biphosphoglycerate, H^+ and PCO_2 or a fall in pH and PO_2 shifts the curve to the right (higher the P_{50}).
- Conversely, a fall in temperature, 2,3-biphosphoglycerate, H^+ and PCO_2 or a rise in pH and PO_2 shifts the curve to the left (lower the P_{50}).

Bohr Effect

Factors affecting the affinity cont'd…

- In the tissues, due to continuous metabolic activities, the partial pressure of carbon dioxide is very high and the partial pressure of oxygen is low.
- Due to this pressure gradient, carbon dioxide enters the blood and oxygen is released from the blood to the tissues.
- Presence of carbon dioxide decreases the affinity of hemoglobin for oxygen.
- It enhances further release of oxygen to the tissues and oxygendissociation curve is shifted to right.

CARBON DIOXIDE TRANSPORT

- Partial pressure of CO_2 in alveoli is 40 mm Hg whereas in the blood it is 46 mm Hg.

  - ✓ Pressure gradient of 6 mm Hg is responsible for the diffusion of carbon dioxide from blood into the alveoli.

- In atmospheric air, partial pressure of carbon dioxide is very insignificant and is only about 0.3 mm Hg whereas, in the alveoli, it is 40 mm Hg.

  - ✓ So, carbon dioxide enters passes to atmosphere from alveoli easily.

CO_2 fate cont'd…

- So, the diffusion of carbon dioxide from tissues to blood is 4 mL/100 mL of blood.
- Carbon dioxide is transported in three forms:

  A. In the form of bicarbonate - 70%

- From plasma, carbon dioxide enters the RBCs.
- In the RBCs, carbon dioxide combines with water to form carbonic acid.
- The reaction inside RBCs is very rapid because of the presence of carbonic anhydrase.

CO_2 fate cont'd…

- Carbonic anhydrase is present only inside the RBCs and not in plasma.
  - ✓ That is why H_2CO_3 formation is at least 200 to 300 times more in RBCs than in plasma.
- Carbonic acid (H_2CO_3) is very unstable.
- Almost all carbonic acid (99.9%) formed in red blood corpuscles, dissociates into H^+ and HCO_3^-.
  - ✓ H^+ dissociated from carbonic acid are buffered by hemoglobin inside the cell.

CO_2 fate cont'd…

- Due to high concentration, bicarbonate ions diffuse through the cell membrane into plasma by Cl^- shift.

- Chloride shift or Hamburger phenomenon is the exchange of a chloride ion for a bicarbonate ion across RBC membrane.

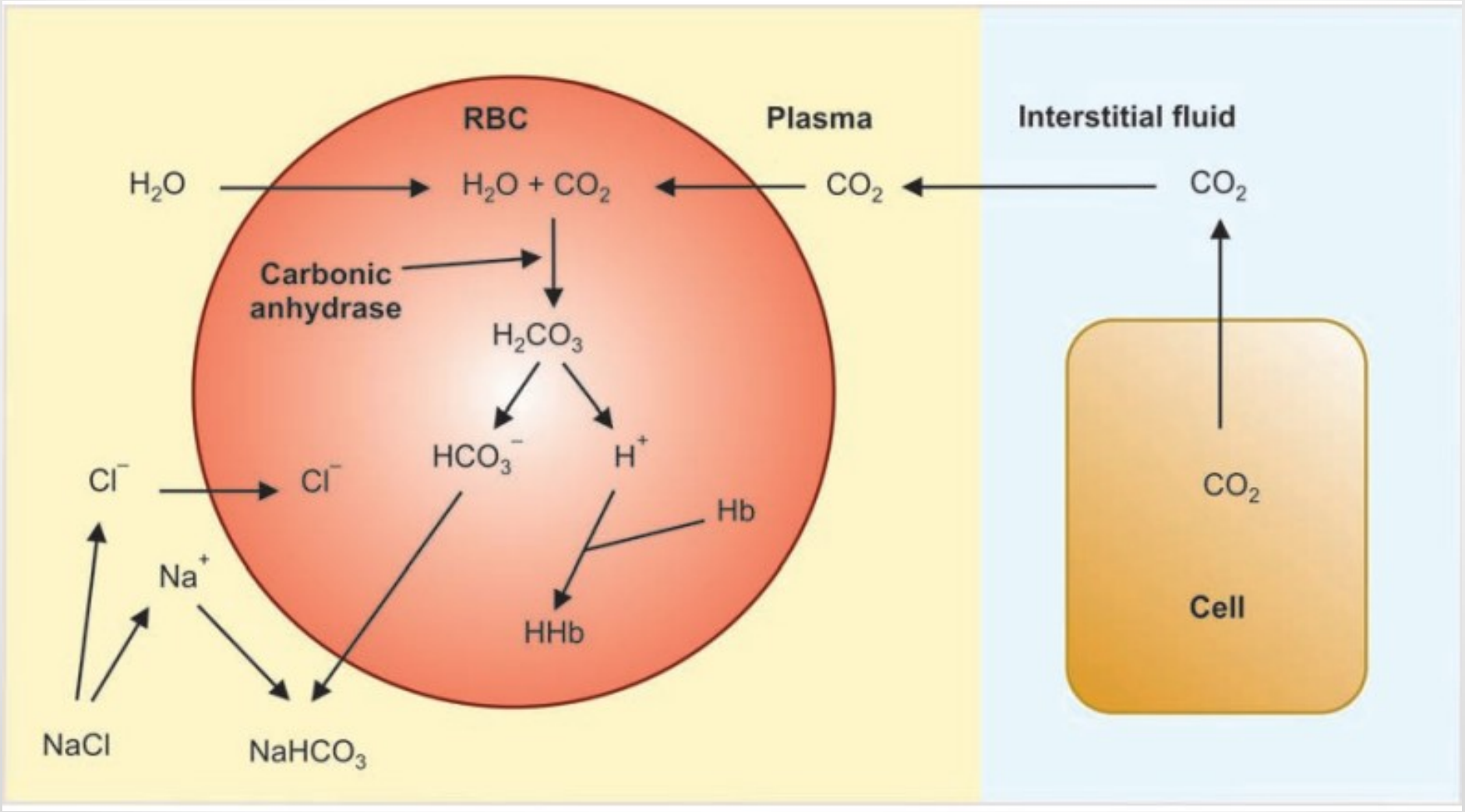
  - ✓ Anion exchanger 1 (band 3 protein), which acts like antiport pump in RBC membrane is responsible for the exchange of bicarbonate ions and chloride ions.

  - ✓ Bicarbonate ions combine with sodium ions in the plasma and form sodium bicarbonate.

CO_2 fate cont'd…

- Reverse chloride shift is the process by which chloride ions are moved back into plasma from RBC shift.
  - ✓ It occurs in lungs.
  - ✓ It helps in elimination of carbon dioxide from the blood.
- Bicarbonate is converted back into carbon dioxide, which has to be expelled out.

CO_2 fate cont'd…



CO_2 fate cont'd…

B. In the form of carbaminohemoglobin - 23%

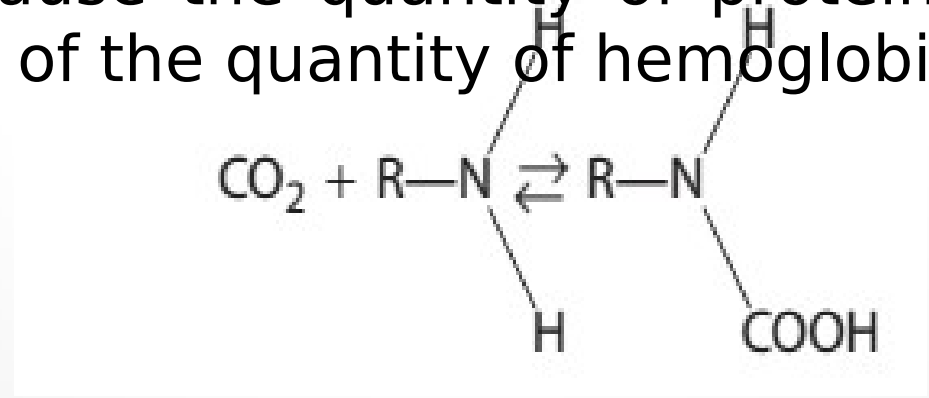
- CO_2 is transported in blood in combination with hemoglobin and plasma proteins.
- CO_2 combines with hemoglobin to form carbamino hemoglobin or carbhemoglobin.
  - ✓ And it combines with plasma proteins to form carbamino proteins.
- Carbamino hemoglobin and carbamino proteins are together called carbamino compounds.

CO_2 fate cont'd…

- ✓ Thus, the combination of CO_2 with proteins and hemoglobin is a reversible one.

- Amount of CO_2 transported in combination with plasma proteins is very less compared to the amount transported in combination with hemoglobin.

- ✓ It is because the quantity of proteins in plasma is only half of the quantity of hemoglobin.



CO_2 fate cont'd…

Haldane Effect

- Haldane effect is the effect by which combination of O_2 with hemoglobin displaces CO_2 from hemoglobin.

- Excess of O_2 content in blood causes shift of the CO_2 dissociation curve to right.

- *Causes for Haldane effect*

- Due to the combination with O_2, hemoglobin becomes strongly acidic.

- It causes displacement of CO_2 from hemoglobin in two

CO_2 fate cont'd…

- So, carbon dioxide is displaced from blood.

ii. Because of the acidity, hydrogen ions are released in excess.

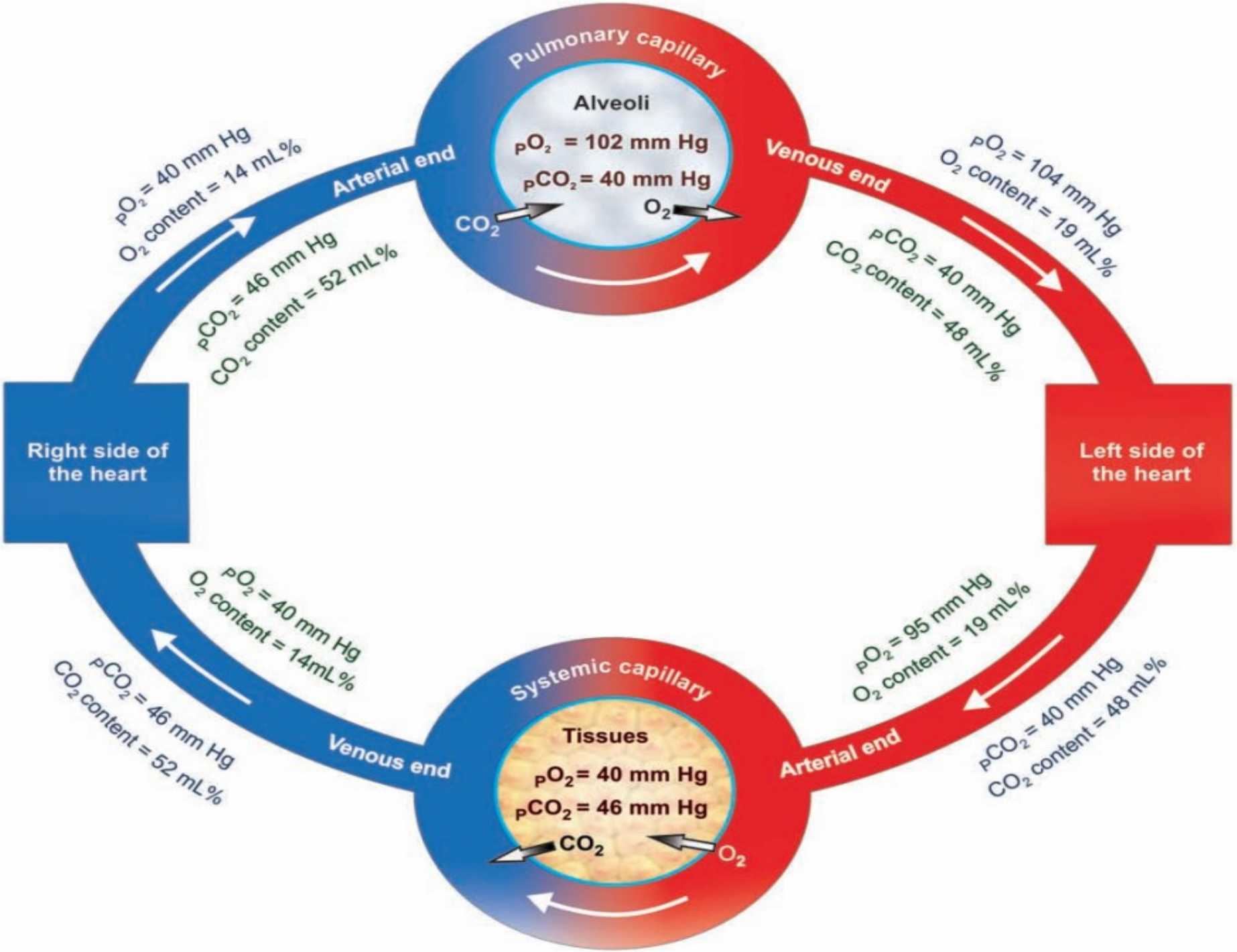
- Hydrogen ions bind with bicarbonate ions to form carbonic acid.
- Carbonic acid in turn dissociates into water and carbon dioxide.
- Carbon dioxide is released from blood into alveoli.

- Haldane effect is essential for:

CO_2 fate cont'd…

C. Dissolved in plasma - 7%

- CO_2 diffuses into blood and dissolves in the fluid of plasma forming a simple solution.
  - ✓ Only about 3 mL/100 mL of plasma of CO_2 is transported as dissolved state.
- About 200 mL of CO_2 per minute at rest and much larger amounts during exercise are transported from the tissues to the lungs and excreted.
- It is worth noting that this amount of CO_2 is equivalent


Pulmonary capillary
Alveoli
$_PO_2$ = 102 mm Hg
$_PCO_2$ = 40 mm Hg
CO_2
O_2
Arterial end
$_PO_2$ = 40 mm Hg
O_2 content = 14 mL%
$_PCO_2$ = 46 mm Hg
CO_2 content = 52 mL%
Venous end
$_PO_2$ = 104 mm Hg
O_2 content = 19 mL%
$_PCO_2$ = 40 mm Hg
CO_2 content = 48 mL%
Right side of the heart
Left side of the heart
Systemic capillary
Tissues
$_PO_2$ = 40 mm Hg
$_PCO_2$ = 46 mm Hg
CO_2
O_2
Venous end
$_PO_2$ = 40 mm Hg
O_2 content = 14mL%
$_PCO_2$ = 46 mm Hg
CO_2 content = 52 mL%
Arterial end
$_PO_2$ = 95 mm Hg
O_2 content = 19 mL%
$_PCO_2$ = 40 mm Hg
CO_2 content = 48 mL%

REGULATION OF RESPIRATION

- Respiration is a reflex process.
  - ✓ But it can be controlled voluntarily for a short period of about 40 seconds.
- At the end of that period, the person is forced to breathe.
- Normally, quiet regular breathing occurs because of two regulatory mechanisms:
  - ✓ Nervous or neural mechanism

Respiratory Center

- Respiratory centers are group of neurons, which control the rate, rhythm and force of respiration.

  ✓ These centers are bilaterally situated in reticular formation of the brainstem.

- Depending upon the situation in brainstem, the respiratory centers are classified into two groups:

  1. Medullary respiratory centers consisting of

     a) Dorsal respiratory group of neurons

     b) Ventral respiratory group of neurons

Regulation of respiration cont'd…

2. Pontine respiratory centers consisting of

   a. Apneustic center

   b. Pneumotaxic center.

- Dorsal respiratory group of neurons are diffusely situated in the nucleus of tractus solitarius which is present in the upper part of the medulla oblongata.

  ✓ Usually, these neurons are collectively called inspiratory center.

  ✓ All the neurons of dorsal respiratory group are
  - inspiratory neurons and generate inspiratory ramp

Regulation of respiration cont'd…

- ***Ventral Respiratory Group of Neurons***

  - ✓ Ventral respiratory group of neurons are present in **nucleus ambiguous** and **nucleus retroambiguous.**

  - ✓ These two nuclei are situated in the medulla oblongata, anterior and lateral to the nucleus of tractus solitarius.

  - ✓ The ventral group neurons were collectively called **expiratory center.**

  - ✓ Ventral respiratory group has both **inspiratory** and **expiratory neurons.**

Regulation of respiration cont'd…

- ✓ Normally, ventral group neurons are inactive during quiet breathing and become active during forced breathing.
- ✓ During forced breathing, these neurons stimulate both inspiratory muscles and expiratory muscles.

- Apneustic Center
  - ✓ Apneustic center is situated in the reticular formation of lower pons.
  - ✓ Apneustic center increases depth of inspiration by acting directly on dorsal group neurons.

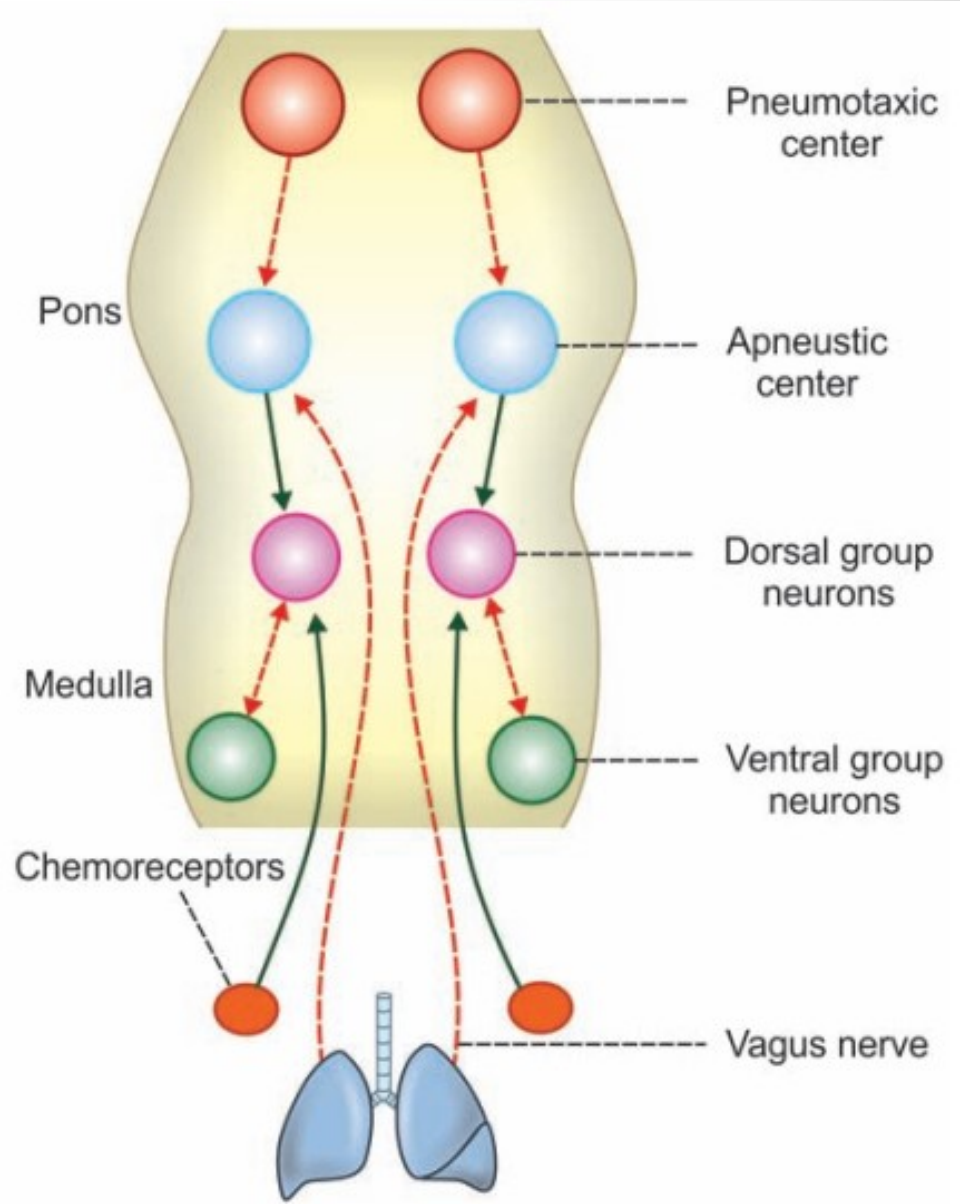
Regulation of respiration cont'd…

- ***Pneumotaxic Center***

  - ✓ Pneumotaxic center is situated in the dorsolateral part of **reticular formation** in **upper pons.**
  - ✓ It is formed by neurons of medial **parabrachial** and **subparabrachial nuclei.**
  - ✓ Subparabrachial nucleus is also called **ventral parabrachial** or **Kölliker-Fuse nucleus.**
  - ✓ Primary function of pneumotaxic center is to control the medullary respiratory centers, particularly the dorsal group neurons.

Regulation of respiration cont'd…

- ✓ Pneumotaxic center inhibits the apneustic center so that the dorsal group neurons are inhibited.
- ✓ Because of this, inspiration stops and expiration starts.
- ✓ Thus, pneumotaxic center influences the switching between
- inspiration and



Regulation of respiration cont'd…

- ***Role of Medullary Centers***

  - ✓ Dorsal respiratory group of neurons are responsible for the normal rhythm of respiration.

  - ✓ These neurons maintain the normal rhythm of respiration by discharging impulses (action potentials) **rhythmically.**

  - ✓ These impulses are transmitted to respiratory muscles by phrenic and intercostal nerves.

- ***Role of Pontine Centers***

  - ✓ Pontine respiratory centers regulate the medullary

Regulation of respiration cont'd…

- ✓ Apneustic center accelerates the activity of dorsal group of neurons and the stimulation of this center causes prolonged inspiration.

- ✓ Pneumotaxic center inhibits the apneustic center and restricts the duration of inspiration.

- HeringBreuer reflex is a protective reflex that restricts inspiration and prevents overstretching of lung tissues.

  - ✓ It is initiated by the stimulation of stretch receptors of air passage.

  - ✓ Stretch receptors are the receptors which give

Regulation of respiration cont'd…

- These receptors are situated on the wall of the bronchi and bronchioles.

✓ Expansion of lungs during inspiration stimulates the stretch receptors.

✓ Impulses from stretch receptors reach the dorsal group neurons via vagal afferent fibers and inhibit them.

- So, inspiration stops and expiration starts.

- Thus, the overstretching of lung tissues is prevented.

Control of ventilation by PO_2, PCO_2 and H^+

- It is achieved via chemoreceptors (*2 types*)

  a. Peripheral - located in the carotid bodies & aortic bodies.

  b. Central - located on the ventral surface of the medulla bilaterally.

- Control of respiration in mammals is regulated by changes in PCO_2 (not PO_2)

- Peripheral O_2 chemoreceptors do not contribute in regulating normal ventilation unless arterial PO_2 falls

ACID BASE BALANCE

- There are three primary systems that regulate the H^+ concentration in the body fluids to prevent acidosis or alkalosis:-

i. *The chemical acid-base buffer systems,* which immediately combine with acid or base to prevent excessive changes in H^+ concentration;

  - ✓ When there is a change in H^+ concentration, the buffer systems of the body fluids react within a fraction of a second to minimize these changes.

- Buffer systems do not eliminate H^+ from or add them

Acid base balance cont'd…

- ✓ Bicarbonate buffer system
- ✓ Phosphate buffer system
- ✓ Proteins:- important intracellular buffers (hemoglobin)

ii. The respiratory center, which regulates the removal of CO_2 from the ECF; and

- ✓ It is the second line of defense, which acts within a few minutes to eliminate CO_2 and, therefore, H_2CO_3 from the body.
- ✓ Respiratory regulation of acid-base balance is a

Acid base balance cont'd…

- The overall buffering power of the respiratory system is one to two times as great as the buffering power of all other chemical buffers in the ECF combined.

  - ✓ That is, one to two times as much acid or base can normally be buffered by this mechanism as by the chemical buffers.

iii. The kidneys, which can excrete either acid or alkaline urine, thereby readjusting the extracellular fluid H^+ concentration toward normal during acidosis or alkalosis.

- The first two lines of defense keep the H^+ concentration from changing too much until the more