CHAPTER

3 Respiratory System

Chapter Outline

- Organs of respiration
- Muscles of respiration
- Pulmonary ventilation
- Physiology of respiration
- Pulmonary circulation
- Exchange of gases
- Regulation of airflow and blood flow in the lung
- Regulation of respiration
- Effect of exercise on respiration
- Lung volumes and capacities
- Pulmonary function test (PFTs)

Respiratory system consists of organs which provide the pathway for supply of oxygen to the body and expulsion of carbon dioxide from the body to the surrounding atmosphere. Oxygen is required for the chemical reactions to release energy that is used for the proper functioning of the cells.

Respiration involves exchange of gases and is a twofold process:

1. **External respiration** is the exchange of gases between the blood and the alveoli of the lungs.
2. **Internal respiration** is the interchange of gases in the tissues.

ORGANS OF RESPIRATION

These include organs which help in the mechanism of respiration (Fig. 3.1). These are as follows:

- **Nose:** External nares, nasal cavity and posterior nares
- Paranasal sinuses
- Nasopharynx
- Larynx
- Trachea and bronchi
- Lungs in the pleural cavity
- **Respiratory muscles:** The diaphragm and intercostal muscles.

Nose

The upper narrow end of the nose just below the forehead is the root of the nose. It is continuous with a prominent ridge which separates the right and left halves of the nose and is called the dorsum.

The lower end of the dorsum is in the form of a round part called the tip of the nose.

At the lower end of nose there are right and left nostrils or anterior nares. The two nostrils are separated by a soft median partition, the columella. This is continuous with nasal septum which separates the two nasal cavities. Each nostril is bounded laterally by ala.

External Nose

The external nose has a skeletal framework that is partly bony and partly cartilaginous. The bones are the nasal bones, and the frontal processes of the maxillae. The cartilages are the superior and inferior nasal cartilage with medial crus and lateral crus, the septal cartilage, and minor alar cartilages (Fig. 3.2).

Nasal Septum

Figure 3.3 shows one nasal cavity.

The *nasal septum* is a median osseocartilaginous partition between the two halves of the nasal cavity. On each side, it is covered by mucous membrane and forms the medial wall of both nasal cavities (Figs 3.4A).

The *bony part* is formed almost entirely by: The vomer and the perpendicular plate of ethmoid.

The *cartilaginous part* is formed by the septal cartilage and the *cuticular part* or lower end is formed by fibrofatty tissue covered by skin. The lower margin of the septum is called the *columella*.

Arterial Supply

The arterial supply of nasal septum is shown in Fig. 3.5.

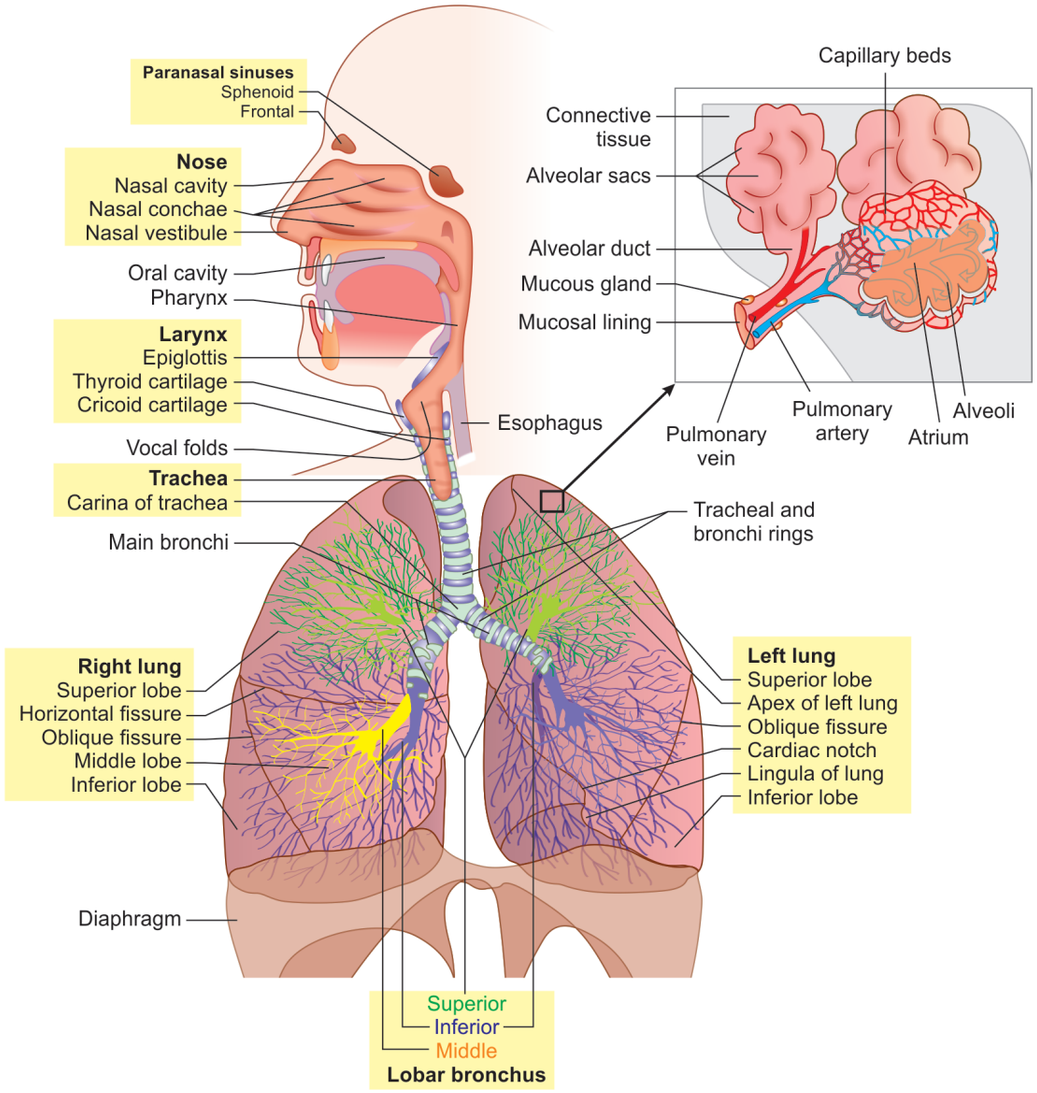


Fig. 3.1: Human respiratory system

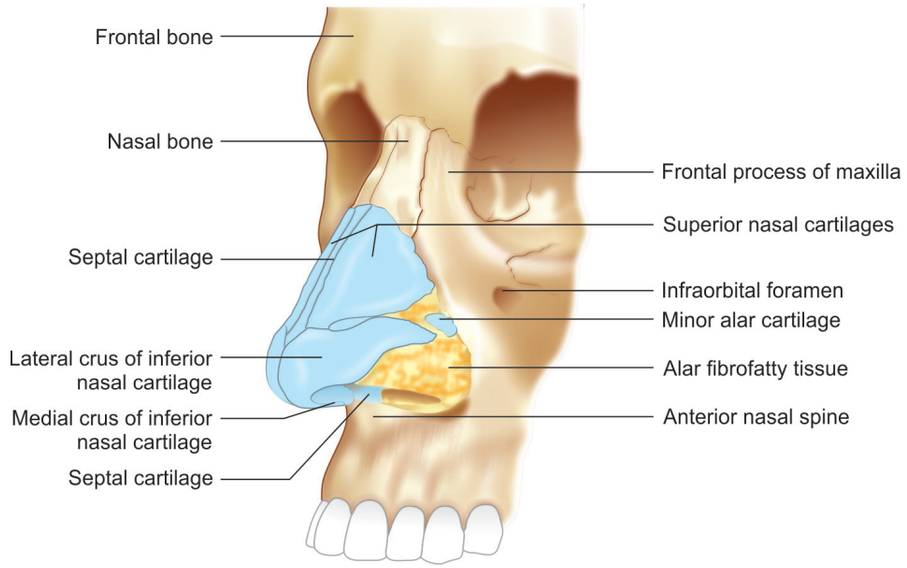


Fig. 3.2: Skeletal framework of external nose

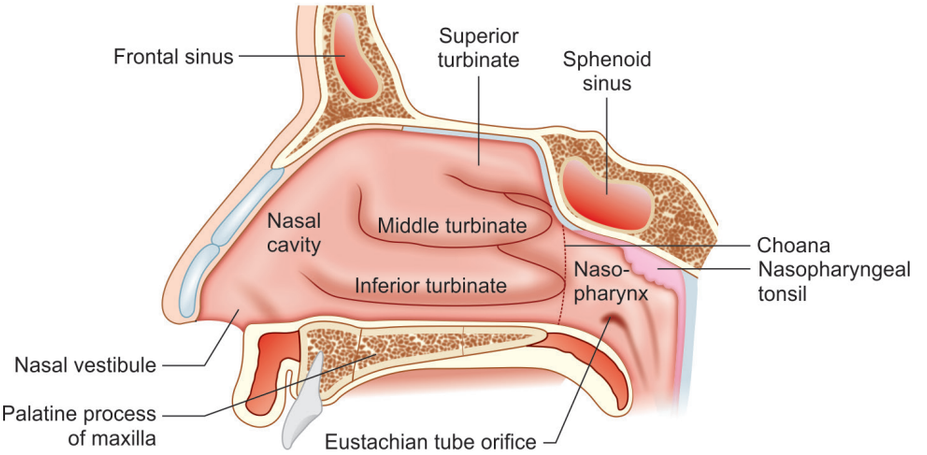
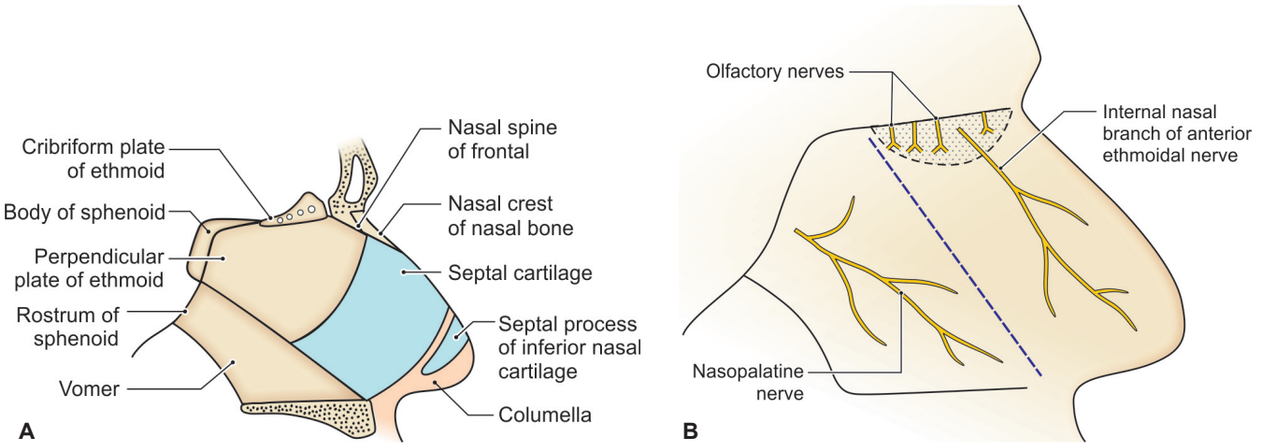


Fig. 3.3: Anatomy of nasal cavity



Figs 3.4A and B: Nasal septum: A. Components; B. nerve supply

Nerve Supply

The nerve supply is shown in Figure 3.4B.

Nasal Cavity

The nasal cavity extends from the external nares or nostrils to the posterior nasal apertures, and is subdivided into right and left halves by the nasal septum (Fig. 3.6).

The *roof* slopes downwards, both in front and behind. The middle horizontal part is formed by the cribriform plate of the ethmoid. The anterior slope is formed by nasal bone, and the nasal cartilages. The posterior slope is formed by the inferior surface of the body of the sphenoid bone.

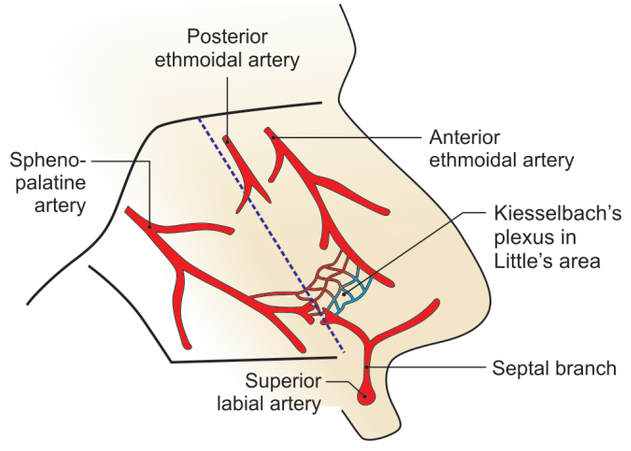


Fig. 3.5: Arterial supply of nasal septum

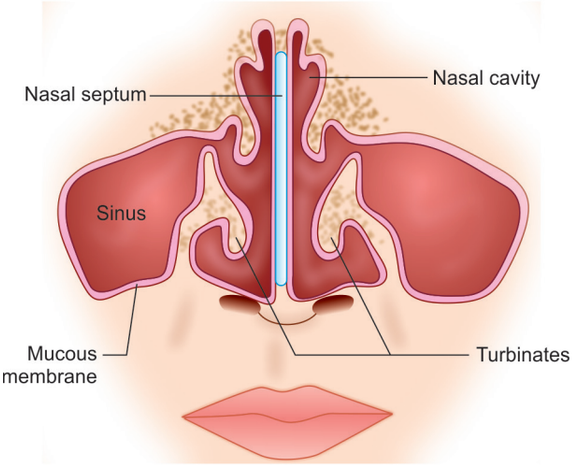


Fig. 3.6: Coronal section through nasal cavity

The *floor* is formed by the palatine process of the maxilla and the horizontal plate of the palatine bone (*see* Fig. 3.3).

- Olfactory nerve—1st nerve
  - The *olfactory cells* (16–20 million in human) are bipolar neurons. They lie in the olfactory part of the nasal mucosa, and serve both as receptors as well as the first neurons in the olfactory pathway.
  - The *olfactory* nerves, about 20 in number, represent central processes of the olfactory cells. They pass through the cribriform plate of ethmoid and make synaptic glomeruli with cells of olfactory bulb. The mitral and tufted cells in the olfactory bulb give off fibers that form the *olfactory tract* and reach the anterior perforated substance and uncus.

Lateral Wall of Nose

The lateral wall of the nose is irregular owing to the presence of three shelf-like bony projections called *conchae* (Fig. 3.7A). The conchae increase the surface area of the nose for effective air-conditioning of the inspired air. Figure 3.7B shows the lateral wall of the nasal cavity after removing the conchae.

The lateral wall can be subdivided into three parts:

- A small depressed area in the anterior part is called the vestibule. It is lined by modified skin containing short, stiff, curved hairs called *vibrissae*.
- The middle part is known as the *atrium* of the middle meatus (Fig. 3.7B).
- The posterior part contains the conchae. Spaces separating the conchae are called meatuses.

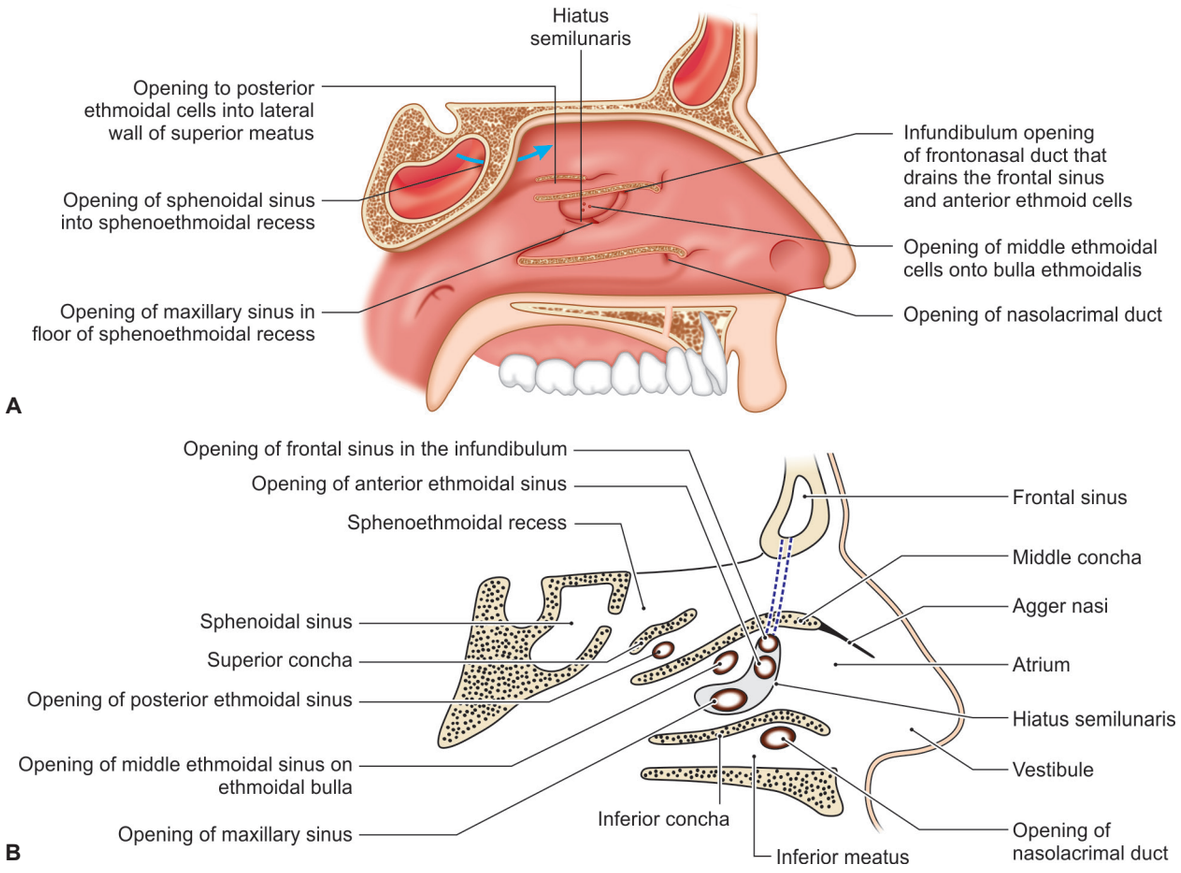
Meatuses and Conchae

The *nasal conchae* are curved bony projections directed downwards and medially. The following three conchae are usually found:

- The *inferior concha* (Latin *shell*) is an independent bone.
- The *middle concha* is a projection from the medial surface of ethmoidal labyrinth (Figs 3.7A and B).
- The *superior concha* is also a projection from the medial surface of the ethmoidal labyrinth. This is the smallest concha situated just above the posterior part of the middle concha.

The *meatuses of the nose* are passages beneath the overhanging conchae. Each meatus communicates freely with the nasal cavity proper.

- The *inferior meatus* lies underneath the inferior concha, and is the largest of the three meatuses. The nasolacrimal duct opens into it at the junction of its anterior one-third and posterior two-thirds. The opening is guarded by the lacrimal fold, or *Hasner's valve*.



Figs 3.7A and B: Conchae and meatuses with their openings

- The *middle meatus* lies underneath the middle concha. It presents the following features:
  - The *ethmoidal bulla* is a round elevation produced by the underlying middle ethmoidal air sinus.
  - The *hiatus semilunaris* is a deep semicircular sulcus below the bulla.
  - The *infundibulum* is a short passage at the anterior end of the hiatus.
  - The *opening of frontal air sinus* is seen in the anterior part of hiatus semilunaris.
  - The *opening of the anterior ethmoidal air sinus* is present behind the opening of frontal air sinus.
  - The *opening of maxillary air sinus* is located in posterior part of the hiatus semilunaris. It is often represented by two openings.
- The *superior meatus* lies below the superior concha. This is the shortest and shallowest of the three meatuses. It receives the *openings of the posterior ethmoidal air sinuses*. The *sphenoethmoidal recess* is a triangular fossa just above the superior concha. It receives the *opening of the sphenoidal air sinus*.

Arterial supply of lateral wall of nose is shown in Fig. 3.8.

Nerve supply of lateral wall of nose is shown in Fig. 3.9.

Paranasal Sinuses

Paranasal sinuses are air-filled spaces present within some bones around the nasal cavities. The sinuses are *frontal*, *maxillary*, *sphenoidal* and *ethmoidal*. All of them open into the nasal cavity through its lateral wall (Figs 3.10A and B).

The *functions* of the sinuses are:

- Make the skull lighter
- Warm up and humidify the inhaled air
- These also add resonance to the voice

In infections of the sinuses or *sinusitis*, the voice is altered.

Functions of Nose

The nose performs the following functions:

- It is a respiratory passage.
- It is also the organ of smell. The receptors for smell are placed in the upper one-third of the nasal cavity. This part is lined by olfactory mucosa. The rest of the nasal cavity is lined by respiratory mucosa. The respiratory mucosa is highly vascular and warms or cools the inspired air.
  - The *olfactory mucosa* lines the upper one-third of the nasal cavity including the roof formed by

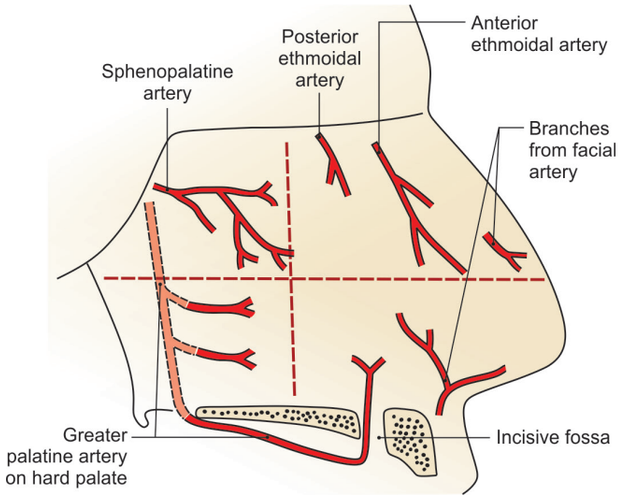


Fig. 3.8: Arterial supply of lateral wall of nose

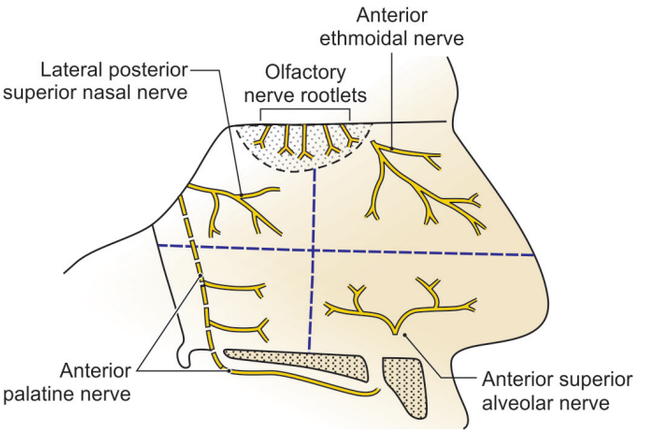
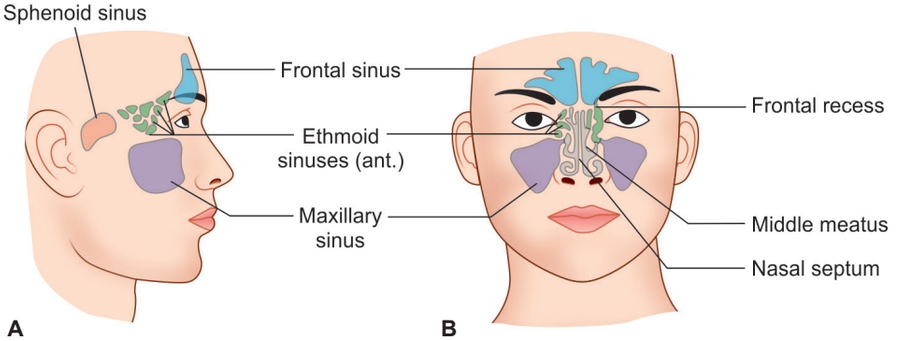


Fig. 3.9: Nerve supply of lateral wall of nose



Figs 3.10A and B: Paranasal sinuses. A. Side view; B. front view

cribriform plate and the medial and lateral walls up to the level of the superior concha. It is thin and less vascular than the respiratory mucosa. It contains receptors called olfactory cells.

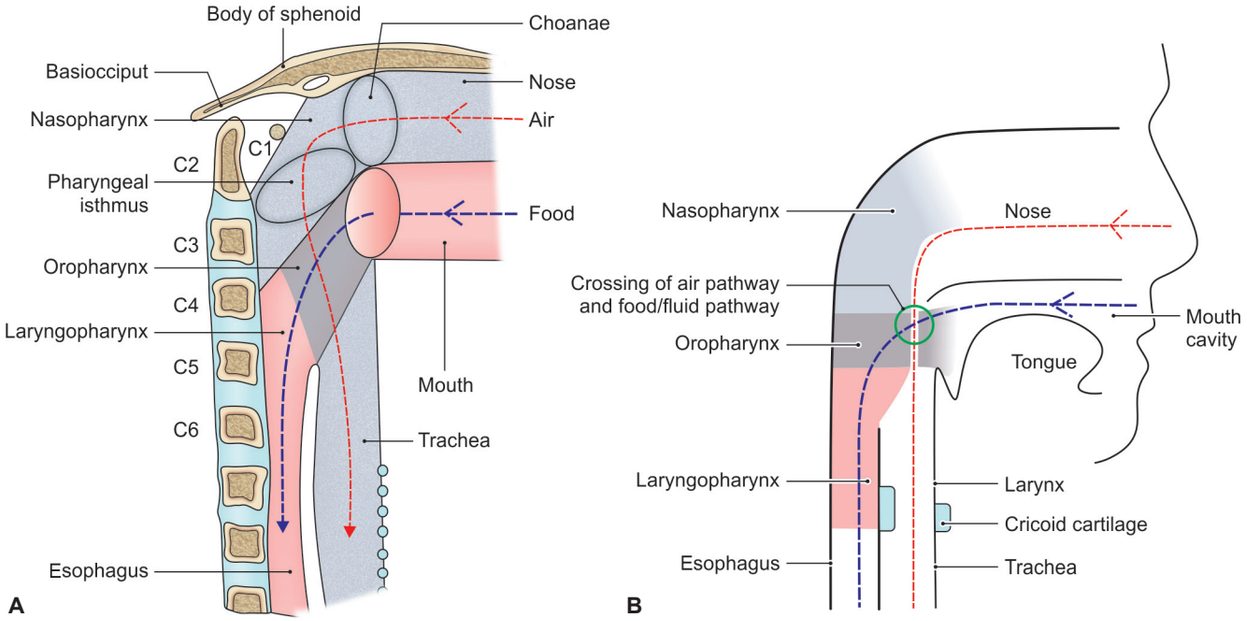
- The secretions of numerous serous glands make the air moist; while the secretions of mucous glands trap dust and other particles. Thus, the nose acts as an air conditioner where the inspired air is warmed, cooled, moistened and cleansed before it is passed onto the delicate lungs.

Pharynx

The *pharynx* (Latin word 'throat') is a wide muscular tube, situated behind the nose, the mouth and the larynx. Clinically, it is a part of the upper respiratory passages where infections are common. The upper part of the pharynx transmits only air, the lower part (below the inlet of the larynx), only food, but the middle part is a common passage for both air and food (Figs 3.11A, B and 3.12A, B). The nasopharynx part of pharynx is connected to the middle ear via the pharyngotympanic tube.

Dimensions of Pharynx

- *Length:* About 12 cm.
- *Width:*
  - Upper part is widest (3.5 cm) and non-collapsible
  - Middle part is narrow
  - The lower end is the narrowest part of the gastrointestinal tract (except for the vermiform appendix).



Figs 3.11A and B: Passage of air and fluid through the pharynx: A. Sagittal section; B. diagrammatic representation

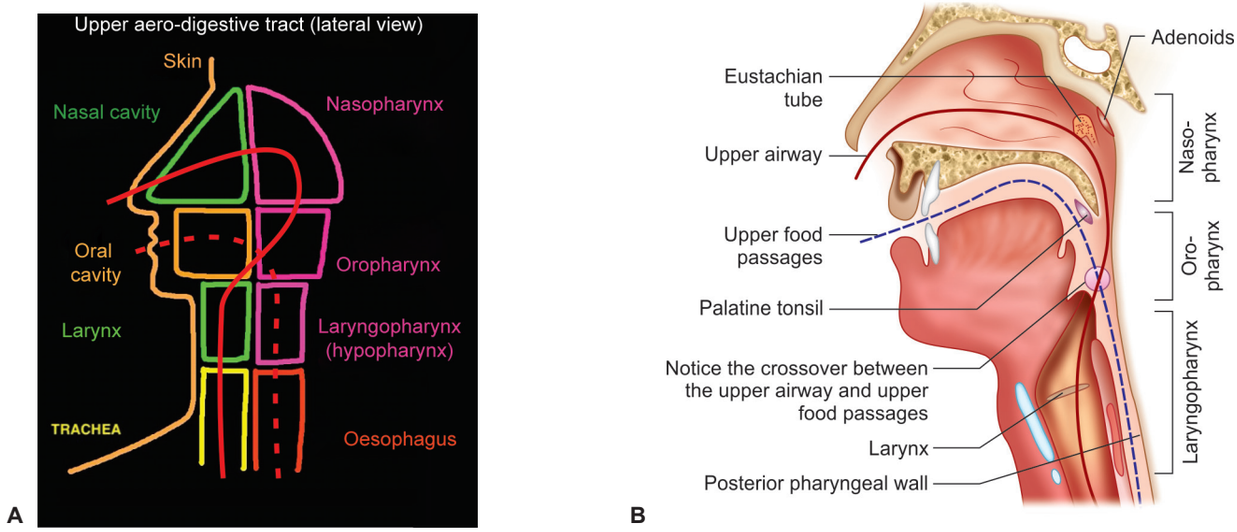


Fig. 3.12A and B: A. Schematic view; B sagittal section pharynx

Boundaries

- **Superiorly:** Base of the skull, including the posterior part of the body of the sphenoid and the basilar part of the occipital bone.
- **Inferiorly:** The pharynx is continuous with the esophagus at the level of the sixth cervical vertebra, corresponding to the lower border of the cricoid cartilage.
- **Posteriorly:** The pharynx glides freely on the prevertebral fascia which separates it from the cervical vertebral bodies.
- **Anteriorly:** It communicates with the nasal cavity, the oral cavity and the larynx. Thus, the anterior wall of the pharynx is incomplete.

Parts of the Pharynx

The cavity of the pharynx is divided into:

- The nasal part—nasopharynx
- The oral part—oropharynx
- The laryngeal part—laryngopharynx

Nasopharynx

It is the uppermost part of pharynx. The posterior nasal apertures open in it. There is also an opening of the **auditory tube** or **Eustachian tube**, in its lateral wall, from the anterior wall of the middle ear. This tube equalizes the pressure on the two sides of the tympanic membrane.

On the posterior wall of nasopharynx **pharyngeal tonsils** (adenoids) are present.

Pharyngeal tonsils consist of lymphoid tissue. These are prominent in children up to 14 years of age and there after these gradually atrophy.

Air passes from nasopharynx into the larynx. Air and fluids/food cross each other in the oropharynx. If one shouts or laughs aloud while eating/drinking, the food/fluid may enter the larynx. This produces a protective bout of cough as food/fluid is forbidden inside the larynx/trachea. Pharynx also functions in speech, giving the voice its individual characteristic note.

Oropharynx

Lies behind oral cavity opposite C2, C3 vertebrae. It extends between soft palate above to the upper border of epiglottis below. Oropharynx communicates anteriorly with oral cavity; above with nasopharynx and below with laryngopharynx. In its lateral wall lies important palatine tonsil. It gives passage both to air and food/fluid.

Laryngopharynx

It lies behind larynx opposite the C5 and C6 vertebrae. It extends between epiglottis and cricoid cartilage and anteriorly is the inlet of larynx.

Pyriform fossa (smuggler's fossa) lies on each side of inlet of larynx. It gives passage only to food/fluid.

Waldeyer's Lymphatic Ring

In relation to the naso-oropharyngeal isthmus, there are several aggregations of lymphoid tissue that constitute Waldeyer's lymphatic ring (Fig. 3.13). The most important aggregations are the right and left palatine tonsils usually referred simply as the tonsils.

The basic function of Waldeyer's ring is the antibody production to common environmental antigens.

Posteriorly and above, there is the nasopharyngeal tonsil; laterally and above, there are the tubal tonsils, and inferiorly, there is the lingual tonsil over the posterior part of the dorsum of the tongue.

Palatine Tonsil (The Tonsil)

The palatine tonsil (Latin *swelling*) occupies the tonsillar sinus or fossa between the palatoglossal and palatopharyngeal arches. It can be seen through the mouth. The tonsil is almond-shaped. It has two surfaces—medial and lateral; two borders—anterior and posterior; and two poles—upper and lower.

- The *medial surface* is covered by stratified squamous epithelium continuous with that of the mouth. This surface has 12–15 crypts. The largest of these is called the *intratonsillar cleft*.
- The *lateral surface* is covered by a sheet of fascia, which forms the hemicapsule of the tonsil.
- The *anterior border* is related to the palatoglossal arch with its muscle (Fig. 3.14).
- The *posterior border* is related to the palatopharyngeal arch with its muscle.
- The *upper pole* is related to the soft palate, and the *lower pole* to the tongue.

Arterial supply: Main source is the tonsillar branch of facial artery (Fig. 3.15).

Venous drainage: One or more veins join—the palatine, pharyngeal, or facial veins.

Lymphatic drainage: Lymphatics pass to jugulodigastric node.

Nerve supply: Glossopharyngeal and lesser palatine nerves.

Histology

The palatine tonsil is situated at the oropharyngeal isthmus. Its oral aspect is covered with stratified squamous non-keratinzed epithelium, which dips into the

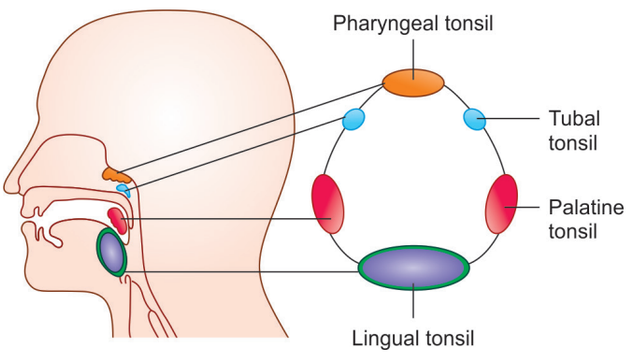


Fig. 3.13: Waldeyer's lymphatic ring

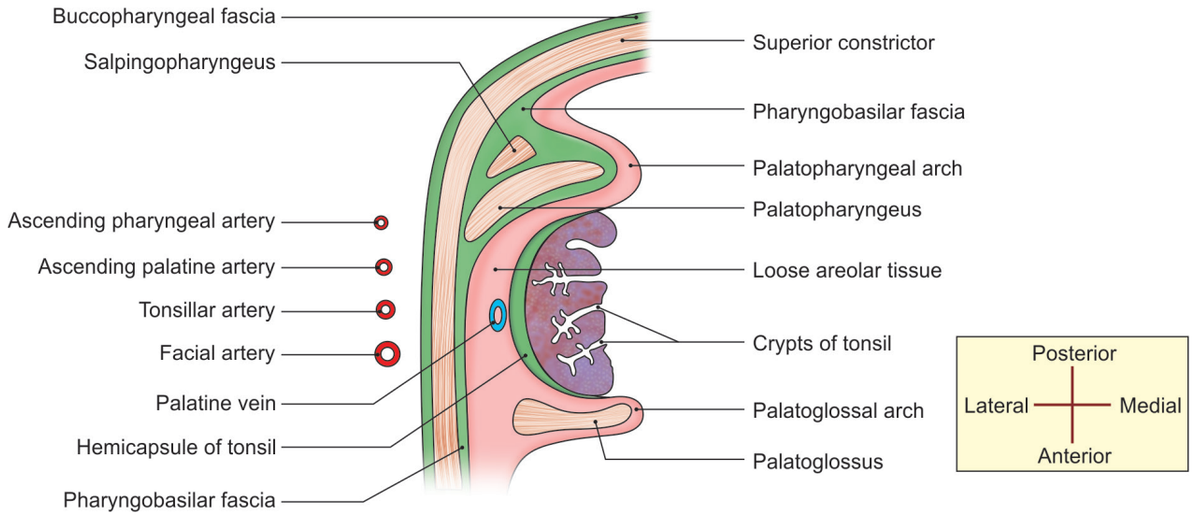


Fig. 3.14: Horizontal section through the tonsil showing its deep relations

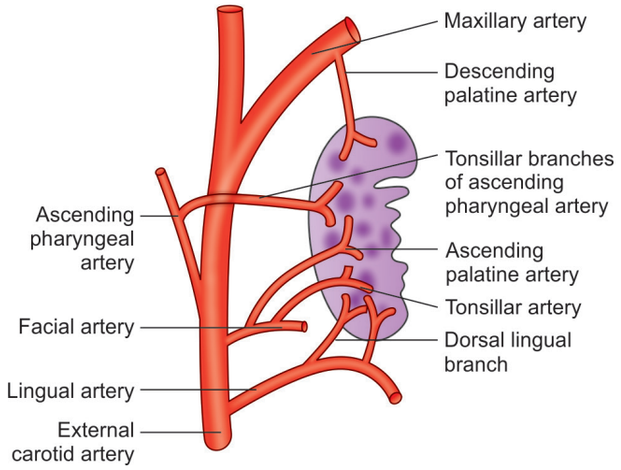


Fig. 3.15: Arterial supply of palatine tonsil

- Capsule shows stratified squamous non-keratinised epithelium on its oral aspect
- The epithelium forms crypts
- No differentiation into cortex and medulla

Fig. 3.16: Histology of palatine tonsil

underlying tissue to form the crypts. The lymphocytes lie on the sides of the crypts in the form of nodules. The structure of tonsil is not differentiated into cortex and medulla (Fig. 3.16).

Development

The tonsil develops from endoderm of ventral part of second pharyngeal pouch. Some part persists as the intratonsillar cleft. The lymphocytes are mesodermal in origin.

- **Lingual tonsils:** These are located on the dorsum of the posterior third of the tongue and are covered by a stratified non-keratinized squamous epithelium. Ducts of the mucous lingual glands often open into the base of their crypts.

Layers of Pharynx

The wall of the pharynx is composed of the following layers from within outwards.

- *Mucosa*
- *Submucosa*
- *Pharyngobasilar fascia* or pharyngeal aponeurosis. This is a fibrous sheet internal to the pharyngeal muscles.
- The *muscular* coat consists of an outer circular layer made-up of the three constrictors (*superior, middle* and *inferior*) and an inner longitudinal layer made-up of the stylopharyngeus, the salpingopharyngeus and the palatopharyngeus muscles.
- The *buccopharyngeal fascia* covers the outer surface of the constrictors of the pharynx.

Pharyngeal Fascia

The pharyngeal fascia is separated into two layers, and pharyngeal muscles are sandwiched between them.

- Thick pharyngobasilar fascia inside
- Thin buccopharyngeal fascia outside
- Reinforces the pharyngeal wall.

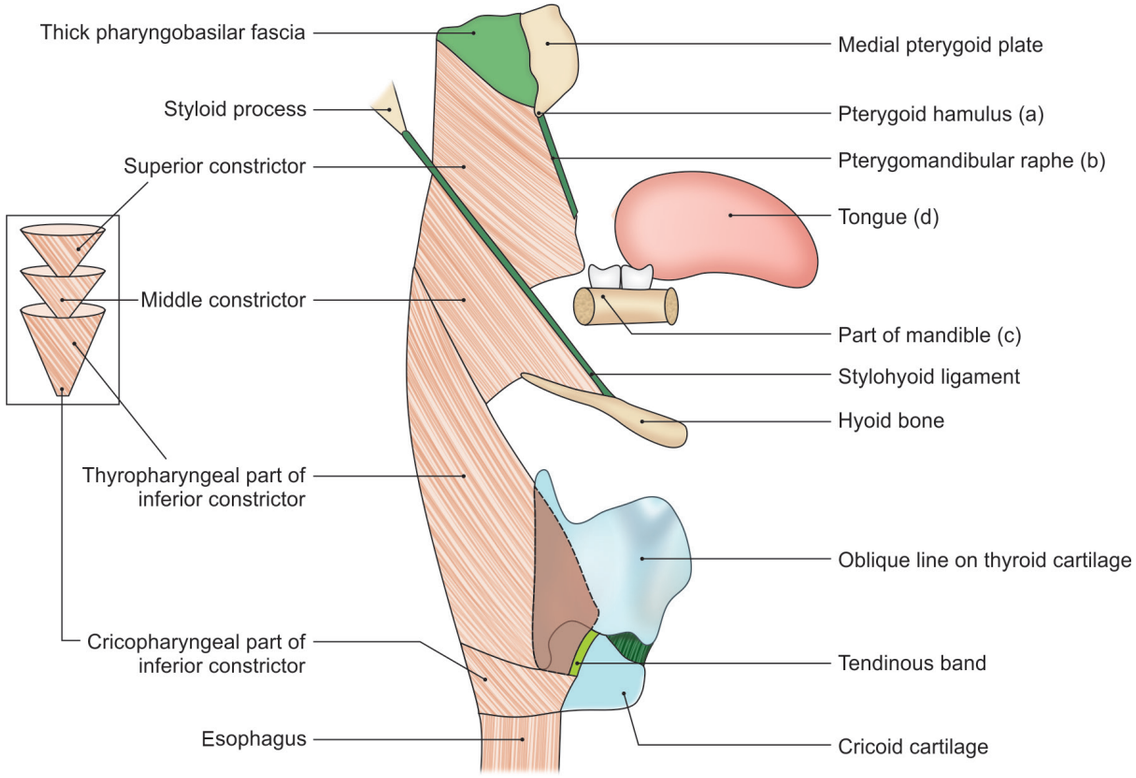


Fig. 3.17: Muscles of pharynx

Muscles of Pharynx

Muscle are superior constrictor, middle constrictor and inferior constrictor (Fig. 3.17). Other muscles are palatopharyngeus, stylopharyngeus and salpingopharyngeus (Fig. 3.17).

Nerve Supply of Pharynx

The nerve supply of pharynx is by the pharyngeal plexus formed by vagoaccessory complex that is 10th nerve and cranial root of 11th nerve.

Blood Supply of Pharynx

The arteries supplying the pharynx are almost the same as those supplying the tonsil. These are as follows:

- Ascending pharyngeal branch of the external carotid artery.
- Ascending palatine and tonsillar branches of the facial artery.
- Dorsal lingual branches of the lingual artery.

The veins form a plexus on the posterolateral aspect of the pharynx. The plexus receives blood from the pharynx, the soft palate and the prevertebral region. It drains into the internal jugular and facial veins.

Functions of Pharynx

- Gives passage for air, food and fluids.
- Warms/cools and humidifies inspired air.
- Helps in hearing, as pharyngotympanic tube joins nasopharynx with anterior wall of middle ear. It equalizes pressure on both sides of tympanic membrane.
- Helps in speech as it causes resonance in the voice.
- Protects the lymphoid tissue forming Waldeyer's ring.

Larynx

Situation and Extent

The larynx lies in the anterior midline of the neck, extending from the root of the tongue to the trachea. In the adult male, it lies in front of the third to sixth cervical vertebrae, but in children and in the adult female, it lies at a little higher level (at C1 to C4 level) (Fig. 3.18).

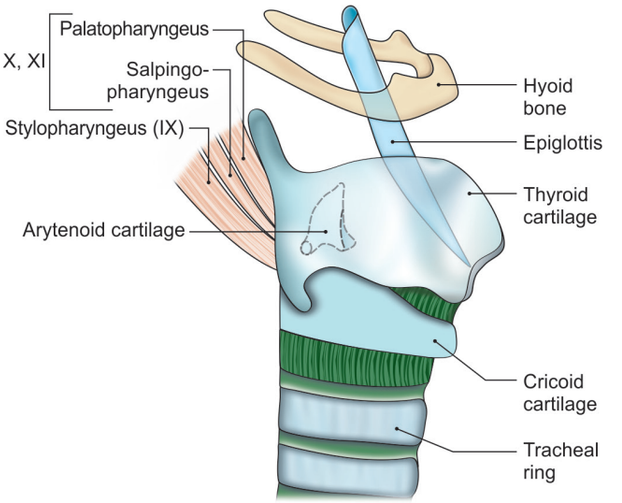


Fig. 3.18: Cartilages of larynx

Dimensions

The length of the larynx is 44 mm in males and 36 mm in females. At puberty, the male larynx grows rapidly and becomes larger, seen as prominent angle of thyroid cartilage (Adam's apple); which makes his voice louder and low pitched. The pubertal growth of the female larynx is negligible, and her voice is high-pitched.

Structure

The larynx is made-up of a skeletal framework of cartilages. The cartilages are connected by joint, ligaments and membranes; and are moved by a number of muscles. The cavity of the larynx is lined by mucous membrane.

Cartilages of Larynx

The larynx contains nine cartilages, of which three are unpaired and three are paired.

Paired Cartilages

Arytenoid cartilage: Arytenoid (Greek word 'cup-shaped') are two small *pyramid-shaped* cartilages lying on the upper border of the lamina of the cricoid cartilage. The *apex* of the arytenoid cartilage is curved posteromedially and articulates with the corniculate cartilage. Its *base* is concave and articulates with the lateral part of the upper border of the cricoid lamina. Base is *prolonged* anteriorly to form the *vocal process*, and *prolonged* to form the *muscular process.* The *surfaces* of the cartilage are anterolateral, medial and posterior (Fig. 3.19B).

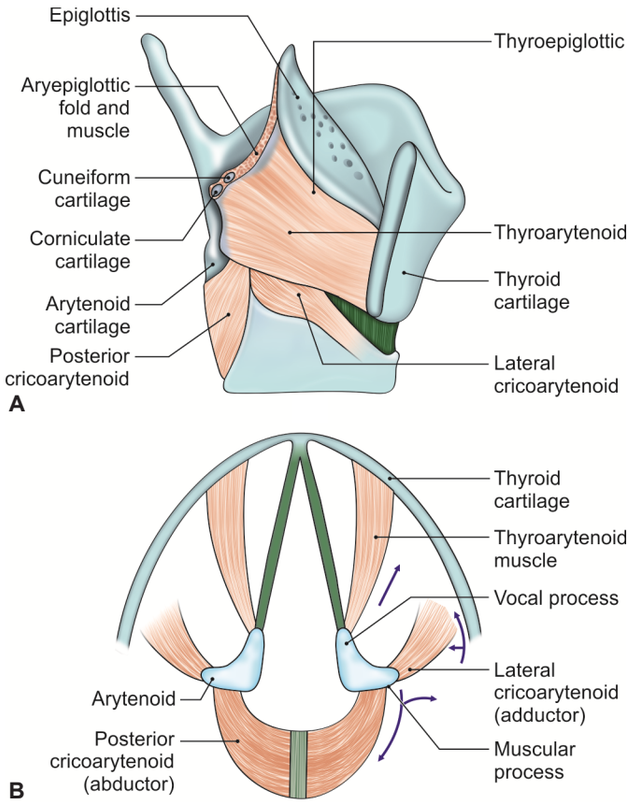
- Corniculate (Latin 'horn-shaped').
- Cuneiform (Latin 'wedge-shaped') (Fig. 3.19A).

Unpaired Cartilages

Thyroid cartilage: Thyroid (Greek word 'shield-like') is a V-shaped cartilage in cross-section. It consists of right and left laminae (*see* Fig. 3.18). Each lamina is roughly quadrilateral.

- The lower parts of the anterior borders of the right and left laminae fuse and form a median projection called the *laryngeal prominence* (Adam's apple).
- The inferior cornua articulates with the cricoid cartilage to form the *cricothyroid joint* (Fig. 3.18).
- The inferior border of the thyroid cartilage is convex in front and concave behind. In the median plane, it is connected to the cricoid cartilage by the *conus elasticus*.
- The *outer surface* of each lamina is marked by an oblique line, which extends from the superior thyroid tubercle in front of the root of superior cornua to the inferior thyroid tubercle behind the middle of inferior border.

Cricoid cartilage: Cricoid is Greek word that means 'ring-like'. This cartilage is shaped like a ring and is a complete cartilage. It encircles the larynx below the thyroid cartilage. It is thicker and stronger than the thyroid cartilage. The ring has a narrow anterior part called the *arch*, and a broad posterior part, called the *lamina*. The lamina projects upward behind the thyroid cartilage, and articulates superiorly with the arytenoid cartilages.



Figs 3.19A and B: Muscles of larynx: A. Posterior view; B. horizontal view

Epiglottic cartilage/epiglottis: Epiglottis (Greek word that means 'leaf-like') is a *leaf-shaped* cartilage placed in the anterior wall of the upper part of the larynx. Its *upper end* is broad and free, and projects upward behind the hyoid bone and the tongue.

The *lower end* or thyroepiglottic ligament is pointed and is attached to the upper part of the angle between the two laminae of the thyroid cartilage.

Histology of Laryngeal Cartilages

The thyroid, cricoid cartilages, and the basal parts the arytenoid cartilages are made-up of the hyaline cartilage. They may ossify after the age of 25 years. The other cartilages of the larynx, e.g. epiglottis, corniculate, cuneiform and processes of the arytenoid are made-up of the elastic cartilage and do not ossify.

Cavity of Larynx

- The inlet is *bounded anteriorly*, by the epiglottis; *posteriorly*, by the interarytenoid fold of mucous membrane; and *on each side*, by the aryepiglottic fold.
- Within the cavity of larynx, there are two folds of mucous membrane on each side. The upper fold is the *vestibular fold*, and the lower fold is the *vocal fold*. The space between the right and left vestibular folds

is the *rima vestibuli*; and the space between the vocal folds is the *rima glottidis*.

- The vocal fold is attached anteriorly to the middle of the angle of the thyroid cartilage on its posterior aspect; and posteriorly to the vocal process of the arytenoid cartilage (Fig. 3.19B).
- The rima is limited posteriorly by an interarytenoid fold of mucous membrane. The rima glottidis, therefore, has an anterior intermembranous part (three-fifth) and a posterior intercartilaginous part (Fig. 3.20A). The rima is the narrowest part of the larynx. It is longer (23 mm) in males than in females (17 mm).
- It pulls the muscular process medially, so that vocal process deviates laterally, thus abducting the vocal cords.
- This is a life-saving muscle, because abduction of vocal cords will permit the air pass in and out.

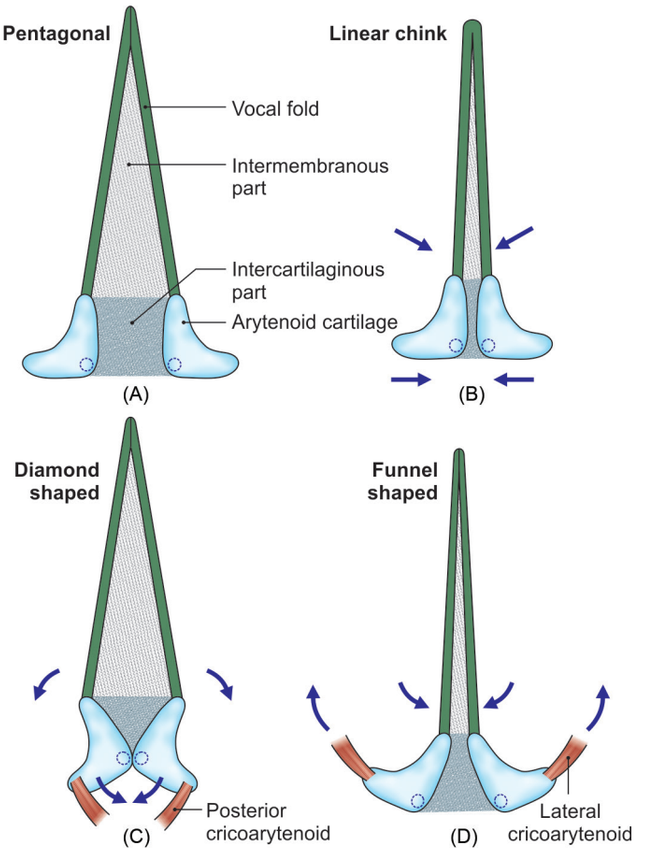
Movement of Vocal Folds

When the vocal folds move the shape and dimensions of the rima glottides change.

Muscles of Larynx

Refer to Table 3.1 to analyze the movement, muscle function and action of larynx.

- During quiet breathing or condition of rest, the intermembranous part of the rima is triangular, and the intercartilaginous part is quadrangular (Fig. 3.20A).
- During phonation of speech, the glottis is reduced to a chink by the adduction of the vocal folds (Fig. 3.20B).
- During forced inspiration, both parts of the rima are triangular, so that the entire rima is lozenge-shaped; the vocal folds are fully abducted (Fig. 3.20C), (i.e. diamond-shaped glottis).
- During whispering, the intermembranous part of the rima glottidis is closed, but the intercartilaginous part is widely open, (i.e. funnel-shaped glottis) (Fig. 3.20D).



Figs 3.20A to D: Rima glottidis: A. In quiet breathing; B. in phonation or speech; C. during forced inspiration; D. during whispering

Functions of Larynx

- Acts as sphincter for lower respiratory passages.
- Produces voice/sound.

Trachea

The trachea is a non-collapsible, wide tube, forming the beginning of the lower respiratory passages. It is kept patent because of the presence of C-shaped cartilaginous

Table 3.1: Muscles acting on the larynx

Movement	*Muscle*	*Action*
1. Elevation of larynx	Thyrohyoid, mylohyoid	Pulls/elevates the larynx
2. Depression of larynx	Sternothyroid, sternohyoid	Pulls/depresses it
3. Opening inlet of larynx	Thyroepiglottic	Elevates/pulls leaf-like epiglottis anteriorly to open the inlet of larynx
4. Closing inlet of larynx	Aryepiglottic	Pulls it posteriorly toward arytenoid cartilage, closing the larynx
5. Abductor of vocal cords	Posterior cricoarytenoid only	It pulls the muscular process medially, so that vocal process deviates laterally, thus abducting the vocal cords
6. Adductor of vocal cords (Fig. 3.19)	Lateral cricoarytenoid, transverse and oblique arytenoids	Pulls muscular process laterally and vocal process is pushed medially, thus adducting the vocal cords as in speaking
7. Tensor of vocal cords	Cricothyroid	Pulls the thyroid cartilage anteriorly, so the vocal cords between thyroid cartilage and arytenoid cartilages get stretched or tensed and voice becomes high-pitched
8. Relaxor of vocal cords and modulation of voice	Thyroarytenoid, vocalis	Pulls arytenoid cartilage forwards, thus lengthening or relaxing vocal cords

'rings' in its wall. The cartilages are deficient posteriorly, this part of the wallbeing made-up of muscle (trachealis) and fibrous tissue. The soft posterior wall allows expansion of the esophagus during passage of food.

Dimensions

The *trachea* (Latin rough air vessel) is about 10–15 cm long. Its upper half lies in the neck and its lower half in the superior mediastinum. The external diameter measures 2 cm in the male and 1.5 cm in the female. The lumen is smaller in the living than in cadavers. It is about 3 mm at 1 year of age, and corresponds to the age in years during childhood, with a maximum of 12 mm at puberty.

Cervical Part of Trachea

The trachea begins at the lower border of the cricoid cartilage opposite the lower border of vertebra C6. It runs downward and slightly backward in front of the esophagus, follows the curvature of the spine, and enters the thorax in the median plane.

In the neck, the trachea is comparatively superficial and has the following relations:

Anterior

- Isthmus of the thyroid gland covering the second and third tracheal rings
- Inferior thyroid veins below the isthmus
- Sternohyoid and sternothyroid muscles
- The skin and superficial fascia

Posterior

- Esophagus
- Longus colli
- Recurrent laryngeal nerve in the tracheoesophageal groove

Lateral

- The corresponding lobe of the thyroid gland
- The common carotid artery within the carotid sheath

Superior: Larynx
Inferior: Right and left bronchus

Vessels and Nerves

The trachea is supplied by branches from the inferior thyroid arteries. Its veins drain into the left brachiocephalic vein. Lymphatics drain into the pretracheal and paratracheal nodes.

Parasympathetic nerves (from the vagus through the recurrent laryngeal nerve) are motor to the trachealis muscle. Sympathetic nerves (from the cervical ganglion) are vasomotor.

Histology of Trachea

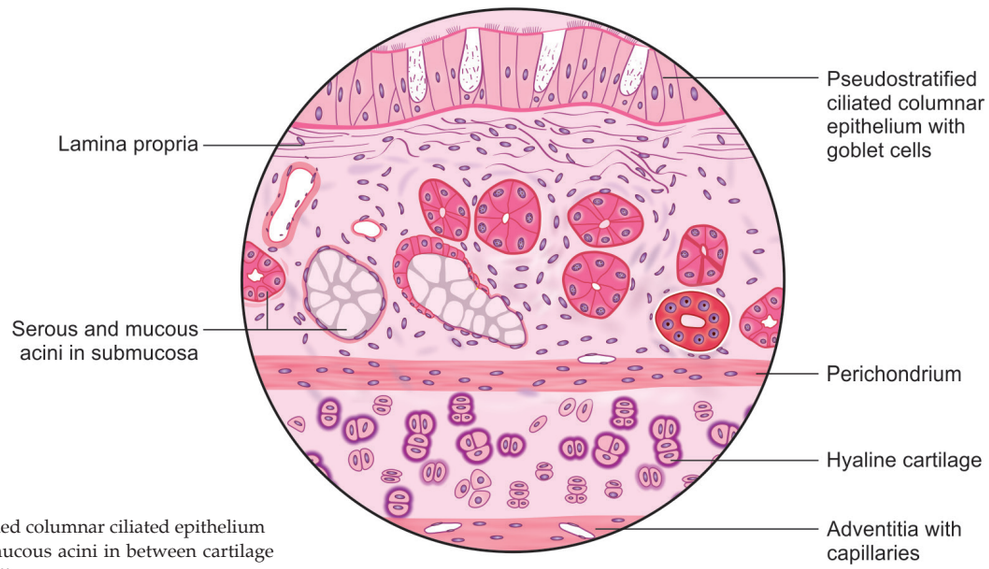
The trachea is lined by **pseudostratified ciliated columnar epithelium**. The cells are of varying height, giving a false appearance of more than one layer of cells. Deep to the epithelium are mucus and serous glands.

The main bulk is formed by the **C-shaped hyaline cartilages** to keep it permanently patent. Cartilage cells lie in groups of two and four each within the matrix, fibers are not visible. At the ends of C-shaped cartilage are the smooth muscle fibers.

Outermost layer is of connective tissue with arterioles (Fig. 3.21).

Functions

'C' shaped cartilages keep the airway patent. The smooth muscles joining 2 ends of 'C' help the esophagus to dilate during passage of bolus. These also provide flexibility to trachea. Ciliary escalator action helps to remove mucus and foreign particles toward larynx where it is either swallowed into laryngopharynx or expectorated.



- Pseudostratified columnar ciliated epithelium
- Serous and mucous acini in between cartilage and epithelium
- C-shaped hyaline cartilage outside

Fig. 3.21: Histology of trachea

Cough reflex: If irritated, the nerve endings in larynx, trachea, bronchi pass impulses via Xth nerve to respiratory center in brainstem. There is deep inspiration, closure of vocal cords, contraction of abdominal and thoracic respiratory muscles and the increased pressure in lungs leads to abduction of vocal cords to expel the irritant through the mouth.

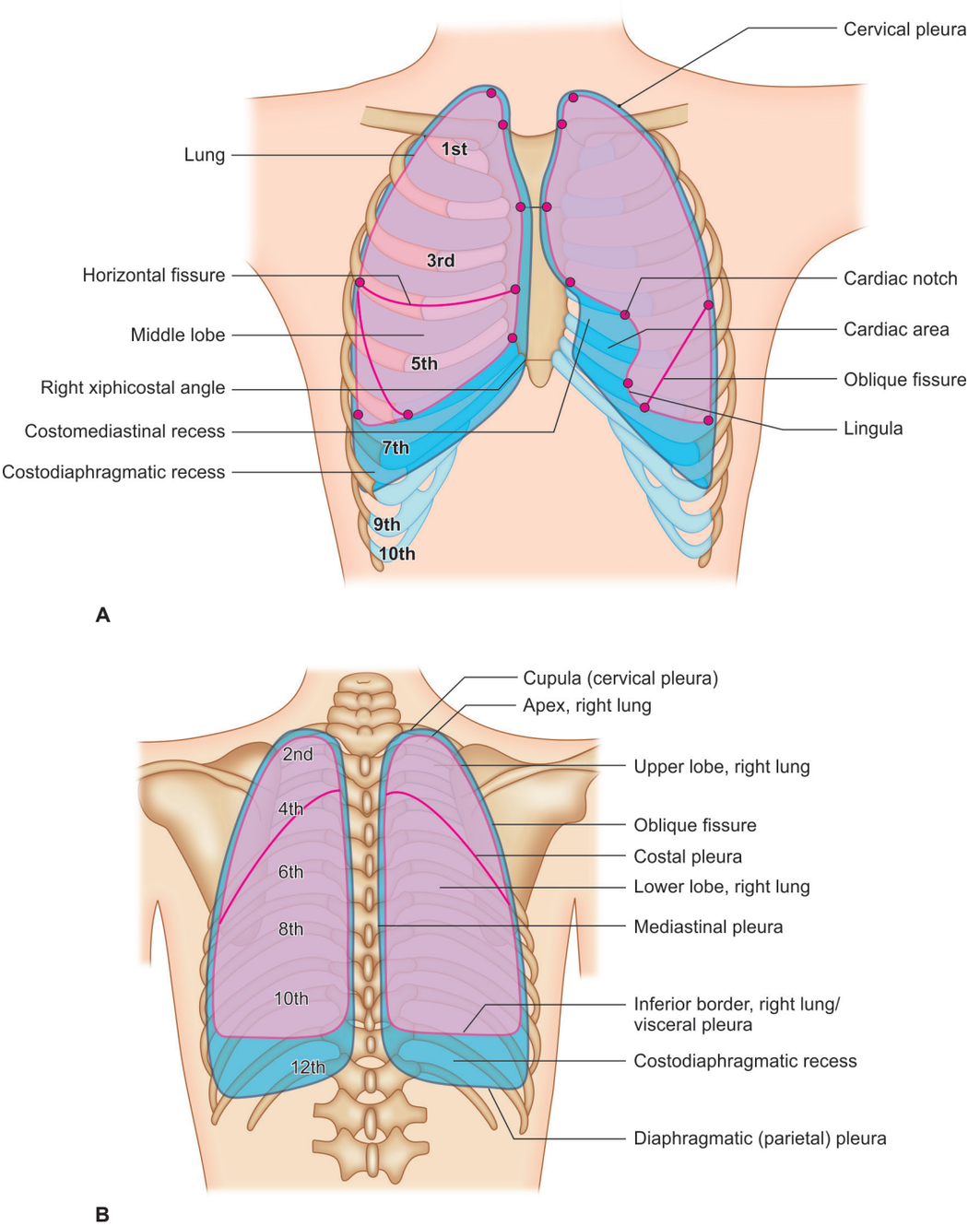
Lungs

Lungs are two voluminous cone-shaped organs occupying most of the thoracic cavity leaving a small space for the heart. Each lung is enclosed in a serous pleural cavity. The **pleural cavity** contains serous fluid which helps in expansion and contraction of the lung.

Pleura: It is a closed serous sac which encloses the lung. It has two layers parietal pleura and visceral pleura.

The **parietal pleura,** which lines the inner surface of the chest wall and thoracic surface of the diaphragm. Its parts are cervical, costal, mediastinal and diaphragmatic pleura. It is reflected at the **hilum** to become the **visceral pleura**.

The **visceral pleura** lines the outer surface of lung and its fissures (Figs 3.22A and B).



Figs 3.22A and B: Surface marking of the parietal pleura and visceral pleura/lung—A. anterior aspect; B. posterior aspect

The pleural cavity: It is a potential space between the two pleurae. They are separated by a thin film of serous fluid, sufficient to prevent friction between them during breathing.

Parts of Lung

Apex: It is round and rises into the root of neck about 2.5 cm above the level of the middle third of clavicle. It is related with blood vessels and nerves of the neck.

Base is concave and closely related with the upper surface of diaphragm.

Costal surface: It is convex and related with the costal cartilages, ribs and intercostal muscles. This surface has impressions of the ribs.

Medial/mediastinal surface: It is concave and has the hilum. The structures which leave and enter from the root of each lung are:

- Bronchus/bronchi
- Pulmonary artery
- Pulmonary veins
- Bronchial artery and bronchial vein
- Lymphatic vessels
- Nerves

The lung has a thin anterior border and a thick posterior border. Table 3.2 and Figure 3.23 show the differences between right and left lungs.

Portions of Lung

Lungs are made-up of two portions, a conducting portion and a respiratory portion.

- **Conducting portion:** The primary bronchus enters the lung at the **hilum** (Fig. 3.24).
  - In the **right lung** it divides into **three secondary bronchi** for each of the **three lobes of the right lung**, i.e. upper, middle and lower separated by the oblique and horizontal fissures (Fig. 3.24). The three secondary bronchi are divided into **10 segmental bronchi.**
  - **Left lung** contains two lobes, i.e. upper and lower lobes, separated by oblique fissure. Therefore, there are only **two secondary bronchi**. But the **segmental bronchi** are **10**—five for upper and five for lower lobe (Fig. 3.25).

Each segmental bronchus divides repeatedly till its diameter becomes 1.0 mm. At this level, it is called the **terminal bronchiole**, with no cartilage plate or glands in it.

- **Respiratory portion:** Terminal bronchiole divides further and forms **respiratory bronchiole**, **alveolar sac**, and finally the **alveoli**. Here, the wall becomes thinner. Alveoli are lined by two types of cells.
  - **Type I** cells are the sites for exchange of gases.
  - **Type II** cells secrete **phospholipid surfactant**.

Table 3.2: Anatomical differences between the right and the left lungs

Right lung	*Left lung*
It has 2 fissures and 3 lobes	It has 1 fissure and 2 lobes
Anterior border is straight	Anterior border is interrupted by the cardiac notch
Larger and heavier, weighs about 700 gm	Smaller and lighter, weighs about 600 gm
Shorter and broader	Longer and narrower

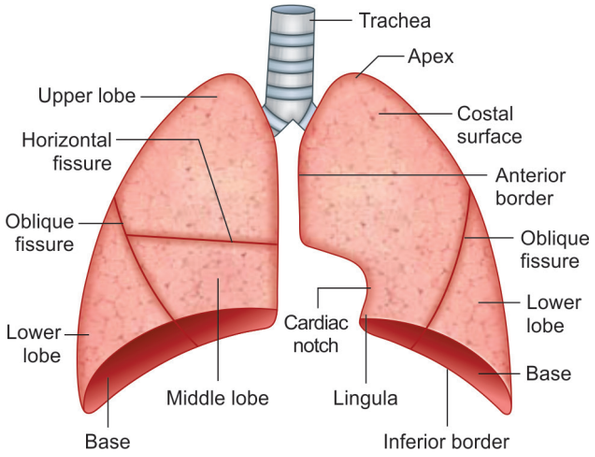


Fig. 3.23: Anatomical differences between right and left lungs

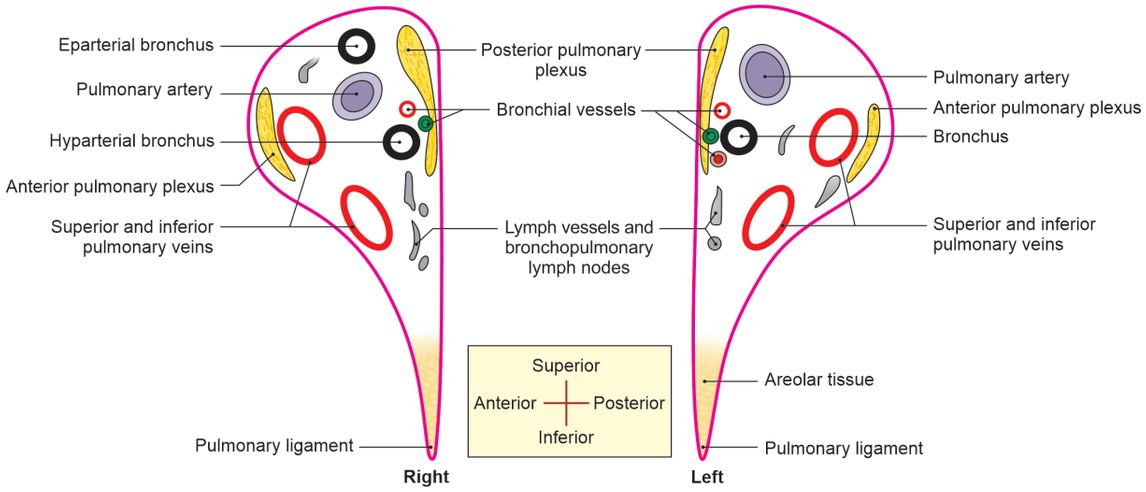
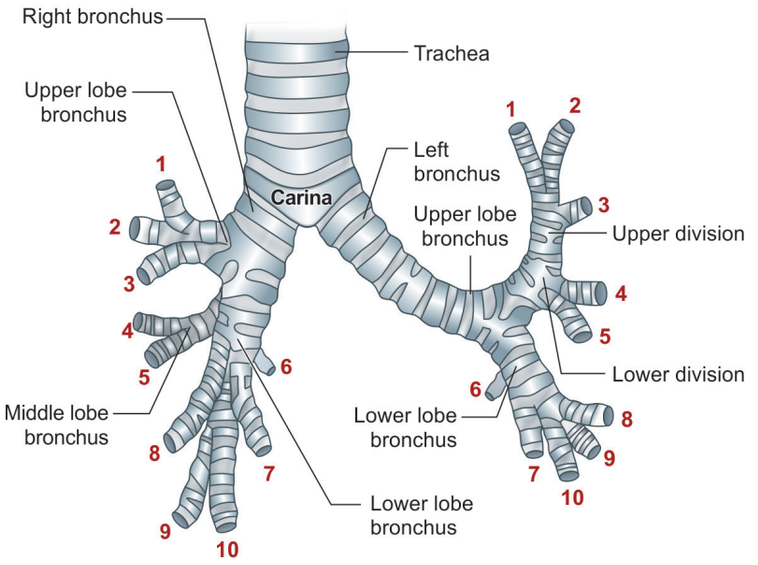


Fig. 3.24: Structures passing through the hila of right and left lungs



Right lung	
Lobes	**Segments**
A. Upper	1. Apical
	2. Posterior
	3. Anterior
B. Middle	4. Lateral
	5. Medial
C. Lower	6. Superior
	7. Medial basal
	8. Anterior basal
	9. Lateral basal
	10. Posterior basal
Left lung	
A. Upper	1. Apical
• Upper division	2. Posterior
	3. Anterior
• Lower division	4. Superior lingular
	5. Inferior lingular
B. Lower	6. Superior
	7. Medial basal
	8. Anterior basal
	9. Lateral basal
	10. Posterior basal

Fig. 3.25: Bronchopulmonary segments of the lungs

This keeps the alveoli patent. In the respiratory portion, the exchange of gases occurs. Therefore, it is called the respiratory portion.

Hilum of lung contains bronchus/bronchi, one pulmonary artery, two pulmonary veins, nerve plexuses, lymph vessels and lymph nodes.

Bronchi conduct air to and from lungs. Pulmonary artery carries deoxygenated blood from the right ventricle for purification into the lungs. The oxygenated blood is returned via four pulmonary veins (two from each lung) to left atrium.

Bronchopulmonary segment: These are well defined pyramidal-shaped segments. Each segment is aerated by segmental bronchus, and has own arterial supply but vein is intersegmental (Fig. 3.25).

Histology of Lung

Lung is characterized by the presence of numerous thin-walled alveoli. These are mostly lined by a single layer of squamous cells, **type I pneumocytes**. Some cuboidal cells are present, these are **type II pneumocytes**. Type II cells produce serous fluid **surfactant**, which prevents the alveoli from collapsing by decreasing surface tension.

Between the alveoli are fine capillaries for exchange of gases. CO_2 is taken from blood and O_2 is given to the blood, thus oxygenating it (Fig. 3.26).

Besides the alveoli and capillaries there are intrapulmonary bronchi and bronchioles.

- **Intrapulmonary bronchi** are lined by pseudostratified ciliated columnar cells, with glands beneath the epithelium. Cartilage is seen as small plates with smooth muscle fibers in between; outermost is thin connective tissue layer.
- **Bronchioles** are dilated spaces lined by columnar epithelium with no cartilage or gland, only smooth muscle fibers are present.

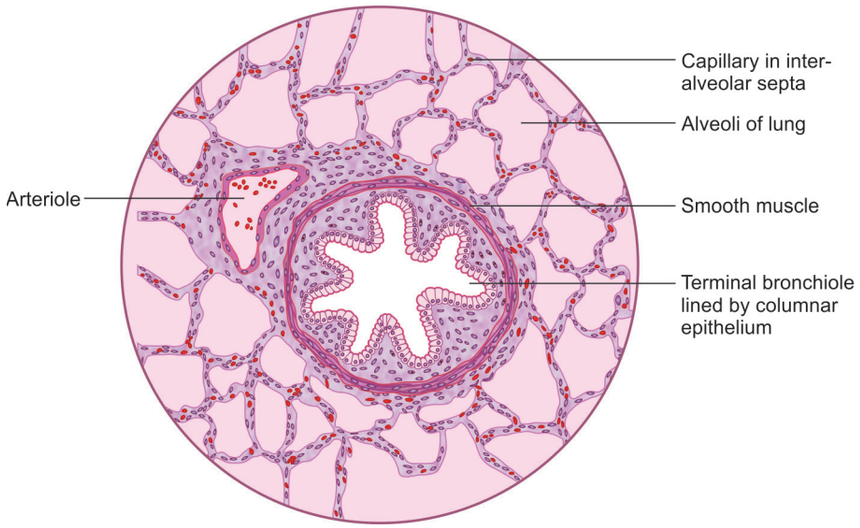
MUSCLES OF RESPIRATION

- For quiet inspiration—diaphragm, external intercostal muscles
- Deep inspiration—erector spinae, scalene muscles, pectoral muscles
- For expiration—passive process
- Forced expiration—muscles of anterior abdominal wall

Respiratory movements during different types of breathing are as follows:

Inspiration

- *Quiet inspiration*
  - The anteroposterior diameter of the thorax is increased by elevation of the second to sixth ribs. The first rib remains fixed. The transverse diameter is increased by elevation of the seventh to tenth ribs. The vertical diameter is increased by descent of the diaphragm.
- *Deep inspiration*
  - Movements during quiet inspiration are increased. The first rib is elevated directly by the scaleni, and indirectly by the sternocleidomastoid. The concavity of the thoracic spine is reduced by the erector spinae.



- Continuous squamous epithelium of alveoli with capillaries in interalveolar septa
- Bronchioles do not have glands or cartilages
- Arteriole seen adjacent to bronchiole

Fig. 3.26: Histology of lung

- *Forced inspiration*
  - All the movements described are exaggerated. The scapulae are elevated and fixed by the trapezius, the levator scapulae and the rhomboids, so that the serratus anterior and the pectoralis minor muscles may act on the ribs. The action of the erector spinae is appreciably increased.

Expiration

- *Quiet expiration*
  - The air is expelled mainly by the elastic recoil of the chest wall and pulmonary alveoli, and partly by the tone of the abdominal muscles.
- *Deep and forced expiration*
  - Deep and forced expiration is brought about by strong contraction of the abdominal muscles and of the intercostal muscles.

PULMONARY VENTILATION

Pulmonary ventilation is a major event of respiration. It is the movement of air in and out of alveoli.

Pulmonary ventilation is referred to as breathing. It is the process of flow of air into the lungs during inspiration (inhalation) and out of the lungs during expiration (exhalation). Air flows because of pressure differences between the atmosphere and the gases inside the lungs.

The primary function of pulmonary ventilation is to make oxygen available to the blood, which is transported by the cardiovascular system throughout the body to all the cells.

Factors Affecting Pulmonary Ventilation

- **Surface tension in the lung:**
  - It is the force exerted by water molecules on the surface of the lung tissue when these water molecules get pulled together. Water (H_2O) is a polar molecule. It forms strong covalent bonds with other water molecules. These covalent bonds create an inward force on surface of lung tissue and it results in lowering of the surface area of the lung tissue. Due to moist air in the lungs, the huge surface tension within the tissue of the lungs is created. As alveoli of the lungs are very elastic, they do not resist this surface tension on their own. This further allows the force of surface tension to deflate the alveoli when air is forced out during expiration while the pleural cavity is contracted.

Pulmonary ventilation is calculated as:

Pulmonary ventilation = Tidal volume* × Frequency of breaths per minute

For example: 0.5 L × 12 breath/min = P.V. = 6 L/min

(* Tidal volume—amount of air either inhaled or exhaled in a normal breath)

PHYSIOLOGY OF RESPIRATION

The respiratory cycle consists of inspiration, expiration and diffusion of gases. In normal quiet breathing, there are about 15 complete respiratory cycles per minute, i.e. respiratory rate of normal adult is 12–16 breaths/minute.

Respiratory Movements

Respiratory movements are inspiration and expiration. The diameters of thoracic cage that increase during inspiration are anteroposterior, transverse and vertical.

- **The anteroposterior diameter is increased** mainly by the pump-handle movements of the sternum brought about the elevation of the vertebrosternal second to sixth ribs (Fig. 3.27).

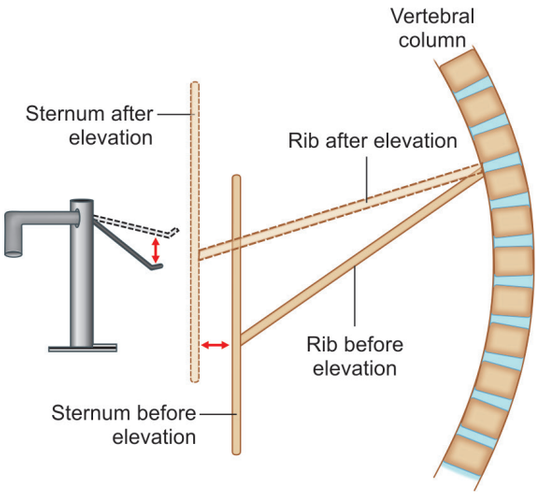


Fig. 3.27: Pump-handle movement

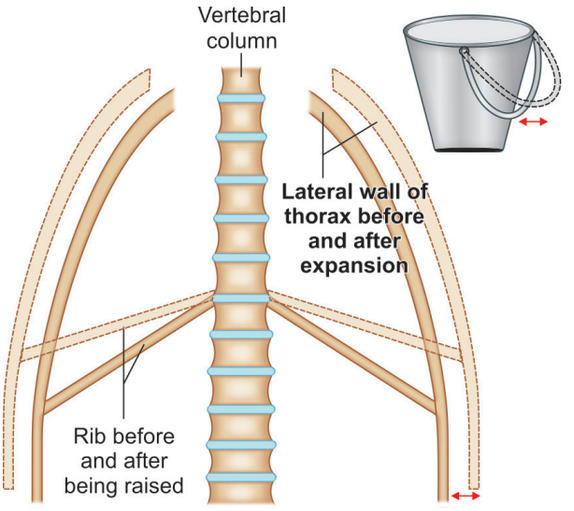


Fig. 3.28: Bucket-handle movement

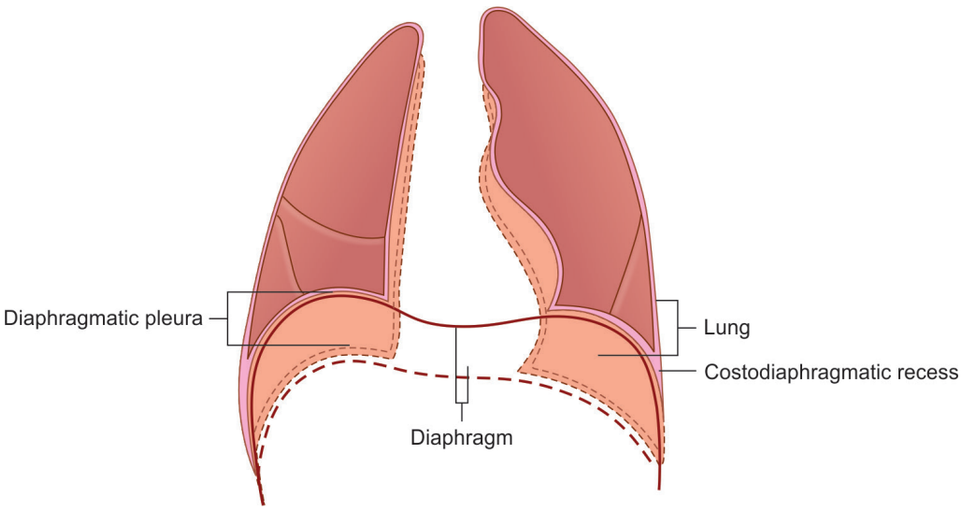


Fig. 3.29: Lung and diaphragm during expiration and descent of diaphragm during inspiration

- **The transverse diameter is increased** mainly by the bucket-handle movements of the seventh to tenth vertebrochondral ribs (Fig. 3.28).
- **The vertical diameter is increased** by descent of the diaphragm as it contracts. This is called *piston mechanism*. During inspiration, the diaphragm contracts and it comes down by 2 cm (Fig. 3.29). It facilitates in inspiration of at least 400 ml of air during each contraction. It is aided by relaxation of muscles of anterior abdominal wall. During expiration, abdominal muscles contract and diaphragm is pushed upward.

In females, respiration is thoracoabdominal and in males it is abdominothoracic type.

Diaphragm and intercostal muscles are respiratory muscles. Respiration results from differences between atmospheric and intrapulmonary pressures, as given ahead.

Before inspiration, intrapulmonary pressure equals atmospheric pressure, at about 760 mm Hg. Intrapleural pressure equals 756 mm Hg (Fig. 3.30).

During inspiration, the diaphragm and external intercostal muscles contract, enlarging the thorax vertically, horizontally and anteroposteriorly (Fig. 5.31).

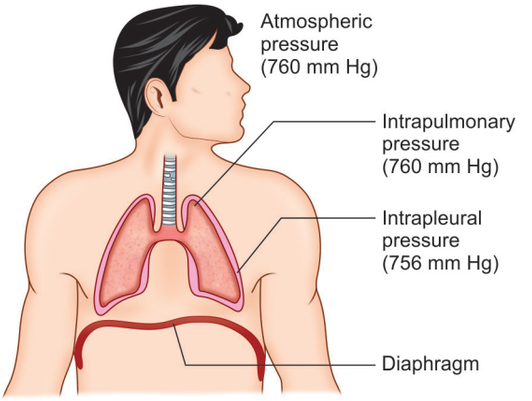


Fig. 3.30: Before inspiration

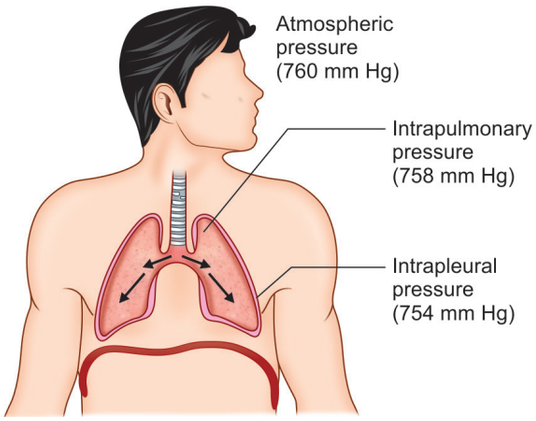


Fig. 3.31: Beginning of inspiration

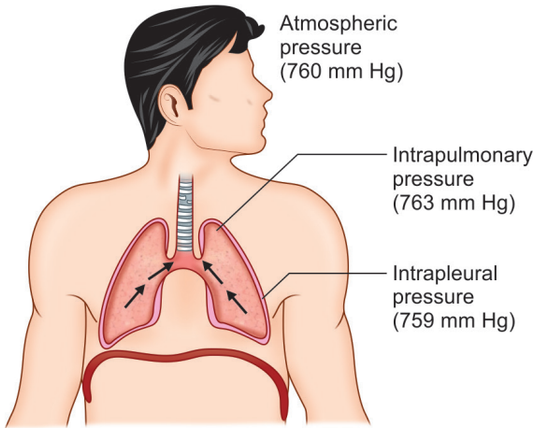


Fig. 3.33: Forced expiration

As the thorax expands, intrapleural pressure decreases and the lungs expand to fill the enlarging thoracic cavity.

The intrapulmonary atmospheric pressure gradient pumps air into the lungs until the two pressures are equal (Fig. 3.32).

During normal expiration, the diaphragm slowly relaxes and the lungs and thorax passively return to resting dimensions and position.

During forced or deep expiration, contraction of abdominal muscles and internal intercostals reduces thoracic volume. Lungs and thorax compression raises intrapulmonary pressure above atmospheric pressure, forcing the air to be expelled (Fig. 3.33).

The chest wall expands during normal inspiration due to simultaneous contraction of intercostal muscles and the diaphragm. During deep breathing, these muscles are assisted by muscles of neck, shoulders and abdomen. The process of inspiration is active, as it requires expenditure of energy for muscle contraction. Expiration is due to relaxation of intercostal muscles and diaphragm and elastic recoil of the lungs. Expiration is passive as it does not require expenditure of energy.

PULMONARY CIRCULATION

Pulmonary circulation moves blood between the heart and the lungs. It transports deoxygenated blood to the lungs to absorb oxygen and release carbon dioxide. The oxygenated blood then flows back to the heart.

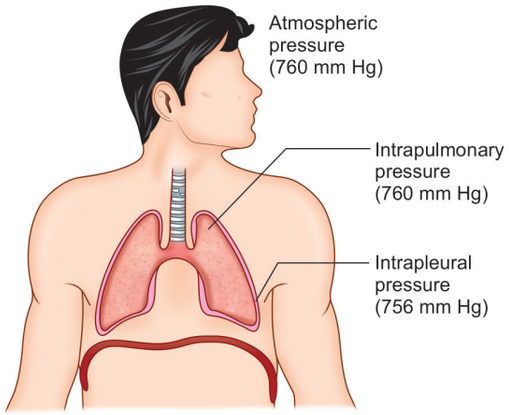


Fig. 3.32: End of inspiration

Pulmonary artery divides into two, each branch carrying deoxygenated blood to the lungs. Within the lung tissues, the pulmonary artery, divides and redivides into a dense capillary network around the walls of alveoli. The pulmonary circulation begins at the pulmonary valve, marking the vascular exit from the right side of the heart, and extends to the orifices of the pulmonary veins in the wall of the left atrium, which marks the entrance into the left side of the heart.

The pulmonary circulation is supplied with both sympathetic and parasympathetic innervation.

The exchange of gases between air in the alveoli and blood in the capillaries takes place here. The pulmonary capillaries join up, forming **two pulmonary veins** in each lung. They leave the lung at hilum and carry oxygenated blood to heart.

The pulmonary circulation differs from the systemic in that it is under minimal resting tone and is almost fully dilated under normal conditions. Circulating and local production of vasodilators and vasoconstrictors contribute in this.

EXCHANGE OF GASES

In Lungs/Pulmonary Ventilation

The alveoli of lungs have basement membrane, which is in close contact with the capillary wall. Gas exchange takes place through capillary wall and alveolar cell membrane. Gases diffuse from higher concentration to lower concentration. In the lungs, the oxygen concentration is more, letting it diffuse into the blood through the capillary wall. The oxygenated blood from here is carried to the left heart to be distributed to all the tissues of the body.

The deoxygenated blood from the tissues is carried to the right heart and is recirculated to the lungs for more oxygen.

Gas exchange is promoted by the following factors:

- Alveolar epithelium, made of very thin epithelial cells

- Pressure of air in the alveolus
- Basement membrane of epithelial cells
- At places, alveolar epithelium fuses with the capillary wall
- Alveolar epithelium is separated from capillary wall by a narrow space (Table 3.3).

The percent of gases inspired and expired air is as follows:

- **External respiration:** Here, the exchange of gases by diffusion occurs between the alveoli and the blood in capillaries. Total area for gas exchange in lungs is about 70–80 square meters. Venous blood reaching the lungs has high levels of CO_2 and low levels of O_2. By diffusion, O_2 diffuses from alveoli into the blood and CO_2 diffuses into alveoli from blood along concentration gradient till equilibrium is reached.

Internal respiration: Here, the exchange of gases by diffusion occurs between blood in capillaries and body cells. Blood reaching the tissues has higher concentration of O_2 and lower concentration of CO_2 than tissues. Because of this difference in concentration, gaseous exchange occurs. O_2 diffuses from blood stream through capillary wall into tissues. CO_2 diffuses from cells into blood stream in capillaries.

In Tissues

Breathing involves the alternating processes of inspiration and expiration, gas exchange at the respiratory membrane. Diffusion of oxygen and carbon dioxide depends on pressure differences between atmospheric air and the blood, or blood and the tissues.

Composition of Air

Air is a mixture of gases. Gases exert their own pressure. The pressure of a specific gas in a mixture is called its partial pressure. It is denoted as p.

Atmospheric air is a mixture of several gases: Oxygen, carbon dioxide, nitrogen (N_2), water vapors (H_2O).

Atmospheric pressure (760 mm Hg) = $pO_2 + pCO_2 + pN_2 + pH_2O$

The partial pressure of O_2 and CO_2 (in mm Hg) in air, blood and tissue cells are as follows (Tables 3.4 and 3.5):

Alveolar air: The alveolar air composition fairly remains constant. Its pressure is different from the atmospheric pressure. It is saturated with water vapors (H_2O). It contains more carbon dioxide (CO_2) and less oxygen (O_2). Saturation with water vapors provides a partial pressure of 47 mm Hg. The partial pressure of other gases gets reduced.

Table 3.3: Gases during inspiration and expiration

Gas	*Inspired air %*	*Expired air %*
Oxygen	21.0	16.0
Carbon dioxide	0.04	3.5
Nitrogen	79.0	79.0
Water vapour	Variable	6.2

Table 3.4: Partial pressure of O_2 and CO_2 (in mm Hg)

	pO_2	*pCO_2*
Atmosphere	160	0.3
Alveoli	105	40.0
Oxygenated blood	100	40.0
Tissue cells	40	45.0
Deoxygenated blood	40	45.0

Table 3.5: The Composition of O_2 and CO_2 (in mm Hg)

	O_2	*CO_2*
Inspired air	4.5%	16%
Alveolar air	5.2%	14%
Expired air	.04%	21%

Summary of inhalation and exhalation

- Inhale → diaphragm and intercostal muscles expand the thoracic cavity → cavity gets bigger → diaphragm flattens → chest wall moves out → intrapleural space volume increases → intrapleural pressure decreases → air moves into the lungs
- Exhale → diaphragm and external intercostals relax → chest cavity moves in → intrapleural space volume decreases → pressure of intrapleural space goes up because volume goes down (think Boyle's law here) → air is pushed out of the lungs.

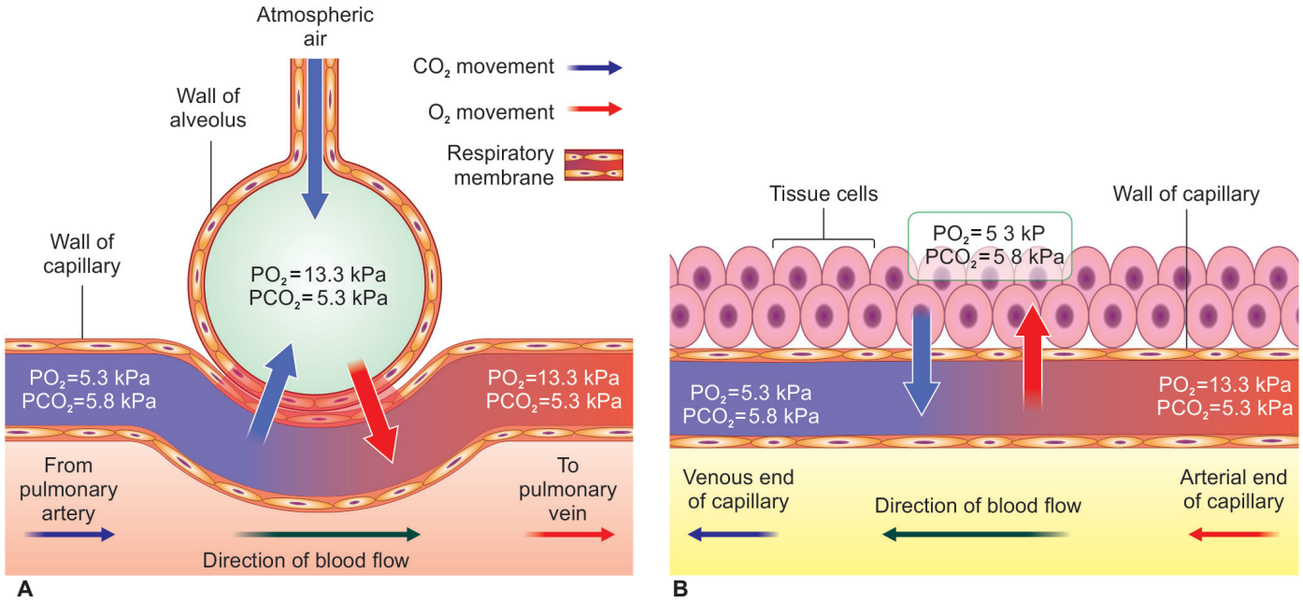
Gaseous Exchange during Respiration

The gases us exchange occurs between alveoli and bloodstream. This process is continuous. But during each inspiration only some of the alveolar gases are exchanged. The final step in the respiration is exchange of gases between the tissues and the external environment with the transportation of oxygen and carbon dioxide in lungs and blood. The oxygen is taken in and carbon dioxide is eliminated. Inhaled oxygen enters the lungs and reaches the alveoli. Similarly, carbon dioxide passes from the blood into the alveoli and is then exhaled (Figs 5.34A and B).

Exhaled air is the mixture of alveolar air and atmospheric air. It is present in dead spaces, i.e. nose, pharynx, trachea, bronchi, and bronchioles. The following three processes occur while the transfer of oxygen takes place from the environmental air to the blood through the lungs:

i. Internal Respiration

The blood having its hemoglobin is saturated with oxygen, it is called oxyhemoglobin. It circulates throughout the body. Finally, it reaches the capillary bed, where the blood moves extremely slowly. The tissue cells take oxygen from the rich hemoglobin. It enables oxidation to go on. The blood receives in exchange the waste product of oxidation, carbon dioxide.



Figs 3.34A and B: Respiration: A. External respiration; B. internal respiration

The surrounding capillaries and alveoli in lungs are lined with only one cell thick layer of cells (1/10,000 of a centimeter, or 0.000039 inch). Moreover, they are in close contact with each other. Oxygen passes quickly through the air–blood barrier into the blood of the capillaries.

The air entering into the alveoli is warm and humidified. The expired air is saturated with water vapors.

Processes involved in exchange of gases

Diffusion: The spontaneous movement of gases, without using energy and is an effortless happening between the alveoli and the capillaries inside the lungs. Diffusion is a process in which exchange of fluid/gases occurs through semipermeable membrane. This exchange occurs from higher pressure toward lower pressure. In diffusion of gases, the gases are exchanged between alveoli and atmosphere. When inside alveoli pressure is less, then gases move from atmosphere into the lungs, it is called inspiration. But, when inside alveoli pressure is more, then gases move from alveoli to the atmosphere called expiration. When pressure gets equalized, it is called pause. Atmospheric nitrogen has no use in our body. Therefore, it remains as such during inspiration and expiration.

Perfusion: The process in which the cardiovascular system pumps blood throughout the lungs.

ii. Exchange of Oxygen

Oxygen is carried in the blood in:

- Chemical combination with hemoglobin as oxyhemoglobin (98.5%)
- Solution in plasma water (1.5%).

Oxyhemoglobin is unstable and under certain conditions readily dissociates, releasing oxygen. Factors that increase dissociation include: (i) low O_2 levels, (ii) low pH and (iii) raised temperature. In active tissues, there is increased production of carbon dioxide and heat, which leads to increased release of oxygen. In this way, oxygen is available to tissues in greatest need. Oxyhemoglobin is of bright red color, whereas deoxygenated blood is bluish-purple in color.

iii. Exchange of Carbon Dioxide

Carbon dioxide is one of the waste products of metabolism. It is excreted by the lungs and is transported by three mechanisms (Fig. 3.35):

- As bicarbonate ions (HCO_3^-) in the plasma (70%)

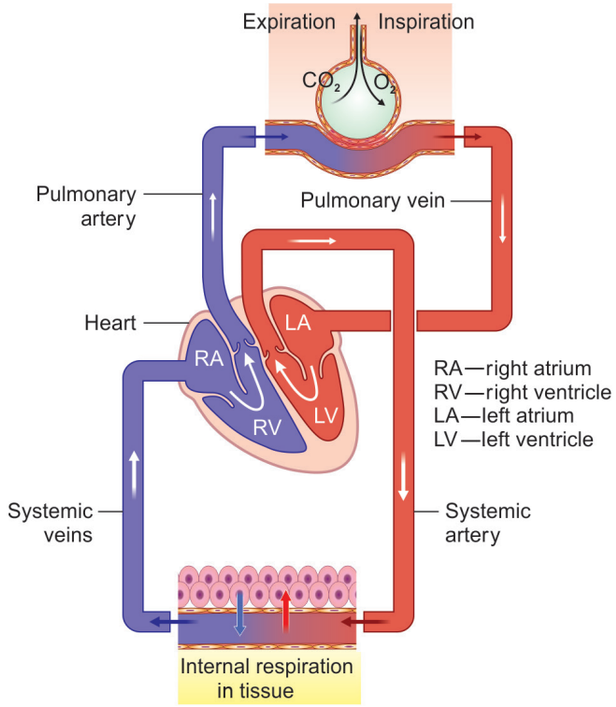


Fig. 3.35: External and internal respiration

- Combined with hemoglobin in erythrocytes as carbaminohemoglobin (23%)
- Dissolved in the plasma (7%).

Carbon dioxide levels must be finely managed, as either an excess or a deficiency leads to significant disruption of acid–base balance.

REGULATION OF AIRFLOW AND BLOOD FLOW IN THE LUNG

During calmness in breathing, only a portion of the lung's total capacity is ventilated during each breath. Therefore, here only a fraction of the total alveoli is being ventilated, generally, in case of the upper lobes. The remaining part of lung is temporarily collapsed. Airways supplying alveoli which are not in use are constricted, and it directs airflow into actively functioning alveoli. Moreover, the pulmonary arterioles are dilated which bring blood into the ventilated alveoli. It maximizes the gas exchange, while blood flow in the non-functioning alveoli reduces. In need of more oxygen, e.g. in exercise, the increased tidal volume expands the additional alveoli. The blood flow is increased and redistributed to these additional alveoli too. This matches the airflow (ventilation) and blood flow (perfusion) to maximize the opportunity for gas exchange.

REGULATION OF RESPIRATION

Physiologically, the respiration is controlled with the help of chemoreceptors and respiratory center (Fig. 3.36).

Control of Rhythmic Breathing

Rhythmic breathing is controlled by respiratory center—group of neurons present bilaterally in medulla oblongata and pons. Respiratory control is an involuntary process, i.e. not under our control. The rhythm of respiration is controlled by the portion of medulla oblongata and pons. It is initiated by the respiratory center in the medulla oblongata of the brainstem.

- **The respiratory center:** The dimensions of thorax are affected by the respiratory muscles called the intercostal muscles. The respiratory center is formed by groups of nerve cells. This controls the rate and depth of respiration. There are neurons present in the center. It is divided into the following areas:
  - **In the medulla:** The ventral group of neurons that fires during forced breathing. The dorsal group of neurons in medulla oblongata, controls the rhythm and rate of and respiration.
  - **In the upper pons:** There is pneumotaxic center situated, bilaterally. These neurons have an inhibitory influence on the inspiratory center in the medulla. This center regulates the rate of breathing. The areas involved are:
    - The pneumotaxic area in pons.
    - The apneustic area in the pons also coordinates with the transmit of inspiration and expiration between alveoli and atmosphere. Promotes inspiration, controls rate of pattern of breathing, it limits inspiration.

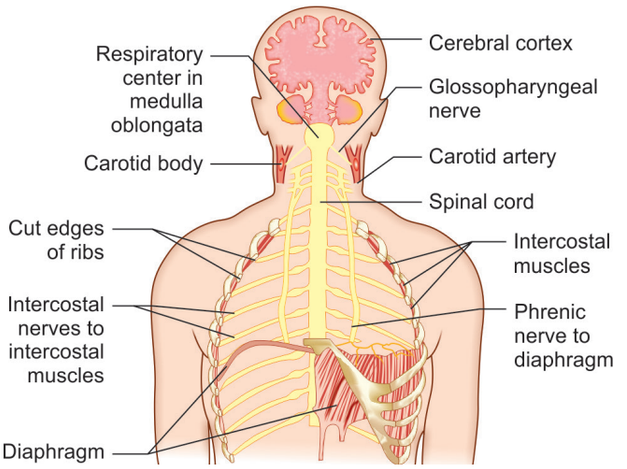


Fig. 3.36: Nerves involved in the control of respiration

- The dorsal group in medulla is called the inspiratory center because it acts like a respiratory 'pacemaker'. The neurons here may be working automatically without the need for stimulus from nerves just like cardiac cells at the sinoatrial node. These neurones switch on for approximately two seconds and off for three in a constant, rhythmic pattern. Number of breaths/min that are generated by the inspiratory center:

One minute = 60 seconds
One respiratory cycle = 5 seconds (two on, and three off)
Respiratory rate per minute = 60/5 = 12 breaths/min
The normal respiratory rate is:
12–18 breaths/min in adults
18–20 breaths/min in children

- The *active inspiratory center neurons* stimulate the nerves to the inspiratory muscles, the phrenic nerves to the diaphragm and intercostal nerves to the external intercostal muscles. These muscles contract and lead to expansion of the thorax, and the air is drawn into the lungs.

When the inspiratory center neurons are not active, the stimulus to the muscles stops and the muscles relax. At this point, expiration occurs passively. This rhythmic pattern continues till any other stimulus affects the neurons of inspiratory center.

Hering-Breuer reflex: There are stretch receptors in the wall of smooth muscle of bronchi and bronchioles. The impulses from these receptors reach the medulla oblongata via the vagus nerve.

Overinflation of lungs stimulates the stretch receptors and causes inhibition of discharge from the inspiratory center. This helps to slow the respiratory rate.

- **Chemical control**
  - **Irritant receptors:** These are present between the epithelial cells. These receptors get stimulated by irritant gases or dust particles. Activation of receptors causes coughing, and increased mucus secretion.

– **Chemoreceptors:** In the body, few chemoreceptors are present which respond to changes in pH, pO_2 and pCO_2. The sensitivity of chemoreceptors to raised arterial CO_2 concentration is the most important factor in maintaining homeostasis of blood gases. The chemoreceptors are located in the medulla oblongata. They monitor the level of CO_2 and O_2. Chemoreceptors respond to changes in PCO_2 and PO_2. The chemoreceptors are stimulated during hypercapnia, i.e. when PCO_2 is increased more than 40 mm Hg.

Breathing is stimulated either by a decrease in pH or pO_2 and an increase in pCO_2. The chemoreceptors are able to maintain the arterial pCO_2/pO_2 and pH within the normal range. The chemical control of respiration regulates pulmonary ventilation according to the metabolic requirements. The chemoreceptors are of two types:

1. **The peripheral chemoreceptors** are present in the aortic and carotid bodies. The aortic bodies are two or more located in the arch of the aorta. The carotid body is located at the bifurcation of common carotid artery. They are sensitive to change in H^+, pCO_2 and pO_2 in blood. Nerve impulses from the peripheral chemoreceptors are conveyed by the glossopharyngeal and vagus nerves to the medulla. It stimulates the respiratory center.

   These are more sensitive to changes in level of carbon dioxide. A slight rise in level of CO_2 activates these receptors. It triggers the nerve impulse to the respiratory center via glossopharyngeal and vagus nerves. The result is immediate increase in the depth and rate of respiration. Peripheral chemoreceptors also help in regulation of blood pressure.
2. The **central chemoreceptors** are present on the surface of medulla oblongata. They respond to changes in pCO_2 and H^+ in cerebrospinal fluid. These respond by stimulating the respiratory center. They increase the ventilation of lungs and reduce arterial pCO_2. This controls normal blood gas levels.

Other Factors that Influence Respiration

There are many other factors, which contribute in regulation of respiration. These are as follows:

- **Limbic system:** Emotional anxiety or anticipation of activity, both may stimulate the limbic system. This sends the input to the inspiratory center. It increases the rate and depth of ventilation.
- **Blood pressure:** The carotid and aortic sinuses contain baroreceptors. It detects the change in blood pressure. It also affects respiration. For example, increase in blood pressure decreases the respiration. Decrease in blood pressure increases the respiration.
- **Temperature:** Increase in body temperature will increase the rate of respiration. A decrease in body temperature decreases the respiratory rate.
- **Pain:** A sudden, severe pain causes apnea. But a prolonged pain results in increase of respiratory rate.
- **Irritation of airway:** Mechanical irritation of the pharynx or larynx stoppage of breathing for a while. It leads to coughing or sneezing.
- **Stretching of the anal sphincter muscle:** This increases the respiratory rate.

EFFECT OF EXERCISE ON RESPIRATION

Exercise accelerates the function of the respiratory and cardiovascular systems. During exercise, increased cardiac output increases the blood flow to the lungs. This is called pulmonary perfusion which rises about five times. The O_2 diffusion capacity increases three times during maximal exercise.

Muscles consume large amount of O_2 when they contract during exercise and produce large amount of CO_2. Pulmonary ventilation increases up to 30-fold from the resting state.

Neural changes that bring excitatory impulses into the inspiratory area in the medulla oblongata, cause the abrupt increase in ventilation at the start of exercise.

At the end of exercise, pulmonary ventilation abruptly decreases. This is followed by a gradual decline to the resting level.

Uptake of Oxygen by the Pulmonary Blood during Exercise

During exercise, the body may require as much as 20 times the normal amount of oxygen.

Because of increased cardiac output during exercise, the time that the blood remains in the pulmonary capillary may be reduced to less than one-half normal. Yet because of the great safety factor for diffusion of oxygen through the pulmonary membrane, the blood still becomes almost saturated with oxygen by the time it leaves the pulmonary capillaries. The diffusing capacity for oxygen increases almost three-fold during exercise; this results mainly from:

- Increased surface area of capillaries participating in the diffusion.
- A more nearly ideal ventilation–perfusion ratio in the upper part of the lungs.
- Under non-exercising conditions, the blood normally stays in the lung capillaries about three times as long as needed to cause full oxygenation. Therefore, during exercise, even with a shortened time of exposure in the capillaries, the blood can still become fully oxygenated.

The exercising muscles release CO_2 which increases the hydrogen ion concentration in the muscle capillary blood. The temperature of the muscle often rises from 2° to 3°C, which can increase oxygen delivery to the muscle fibers.

LUNG VOLUMES AND CAPACITIES

Lung volume is the static volume of air breathed by an individual, i.e. volume of air present in lung under

specific position of the thorax. Lung volumes depend on age, weight, and gender and body position. When two or more volumes combine, this is called capacity (Fig. 3.37).

Lung Volumes

- **Dead space:** It is constituted by air, which does not participate in diffusion, i.e. air present in nose, trachea and bronchial tree. Normally, it is 150 ml.
- **Tidal volume:** Volume of gas inspired or expired in each breath during normal quiet respiration. It is 400–500 ml (10 ml/kg) (Fig. 3.37).
- **Alveolar ventilation:** It is the volume of air that moves into and out of alveoli per minute.

  Alveolar ventilation = (Tidal volume – Anatomical dead space) × Respiratory rate
  = (500 – 150) × 15
  = 5.25 L/min
- **Inspiratory reserve volume:** It is the maximum volume of gas, which a person can inhale from end inspiratory position. It is 2,400–2,600 ml.
- **Inspiratory capacity:** It is the maximum volume, which can be inhaled from end expiratory position, i.e. it is inspiratory reserve volume + tidal volume. It is 2,500 (IRV) + 500 (TV) = 3,000 ml.
- **Expiratory reserve volume:** Maximum volume of gas that can be exhaled after normal expiration. It is 1,200–1,500 ml.
- **Vital capacity:** It is the maximum amount of gas that can be exhaled after maximum inhalation, i.e. it is:

  IRV + TV + ERV

  It is 4,200–4,500 ml (75–80 ml/kg).
- **Residual volume:** It is volume of gas still present in lungs after maximal expiration. It is 1,200–1,500 ml.

Lung Capacities

- **Inspiratory capacity (IC—max):** Amount of gas inspired into the lungs after a normal tidal expiration: [IC = TV + IRV] 3500 ml (Fig. 3.38).
- **Functional residual capacity (FRC):** Amount of gas remains in the lungs after normal expiration: [FRC = ERV + RV] 2500 ml.
- **Vital capacity (VC—max):** Amount of gas expelled from the lungs after a maximum inspiration: [VC = IRV + TV + ERV] 4500 ml.
- **Total lung capacity (TLC—max):** Amount of gas inspired to expand the lungs to its maximum extend [TLC = TV + IRV + ERV + RV] 6000 ml.
- **Maximum breathing capacity:** Maximum volume of air that can be breathed/minute. It is 120–170 liter/mm (normally, it is measured for 15 seconds and expressed as liter/min).

Abbreviations: ERV, expiratory reserve volume; FRC, functional residual capacity; IC, inspiratory capacity; IRV, inspiratory reserve volume; RV, residual volume; TLV, total lung volume; TV, tidal volume; VC, vital capacity.

Fig. 3.38: Lung volumes

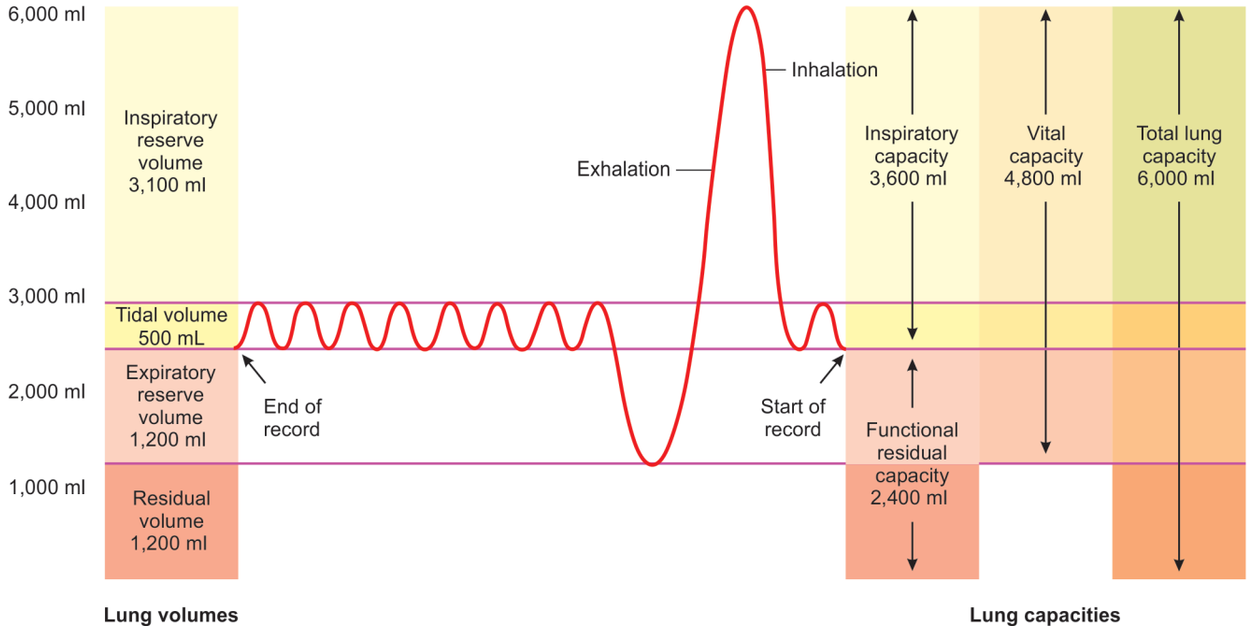


Fig. 3.37: Spirogram of lung volumes and capacities (average values for a healthy adult)

- **Minute volume:** It is tidal volume × Respiratory rate. It is 500 × 12 = 6,000 ml/min.
- **Total lung volume:** IRV + TV + ERV + RV. It is 5,500–6,000 ml.
- **Functional residual capacity (FRC):** It is the volume of gas in lungs after end expiration. It is ERV + RV. It is 2,400–2,600 ml.

Lung function tests are based on lung volumes (Fig. 3.38). They are useful in diagnosis and monitoring of respiratory system diseases.

Note: All these lung volumes are approximately 5% less in females (except residual volume).

Effects of Smoking

- The major adverse effects of smoking on the respiratory system include lung cancer, chronic bronchitis and emphysema.
- Carbon monoxide present in the smoke binds to hemoglobin and reduces its oxygen-carrying capacity.
- Nicotine constricts the bronchioles that lead to decrease in the flow or air into and out of lungs.
- Irritants in the smoke destroy cilia that are present on the lining of the respiratory system. Without cilia, the epithelium cannot clear the passageway or mucus and debris, which helps in growth of microorganisms, leading to respiratory infections.

PULMONARY FUNCTION TESTS (PFTs)

Pulmonary function tests (PFTs) are a group of tests that measure how well your lungs work, how well the lungs take in and exhale air, and how efficiently they transfer oxygen into the blood.

PFTs are useful in assessing the functional status of the respiratory system both in physiological and pathological conditions. It is based on the measurement of lung volumes of air breathed in and out in normal breathing and forced breathing. It is carried out by using a spirometer.

Purposes of PFTs

- Detect disease and serves as a diagnostic tool, and has investigation role.
- Evaluates severity, extent and monitor the course of disease.
- Evaluates treatment.
- Measures effects and results of treatment exposures.
- Helps to diagnose asthma, chronic bronchitis, respiratory infections, lung fibrosis, bronchiectasis, allergy, emphysema, cystic fibrosis, asbestosis which is a condition caused by exposure to asbestos, sarcoidosis, which is an inflammation of lungs, liver, lymph nodes, eyes, skin, or other tissues and pulmonary tumors.
- Used to evaluate physiological aspect of breathing from respiratory muscle function to the diffusion of gas at the alveolar wall.
- Helps physiotherapist to distinguish between obstructive and restrictive lung problem and to select appropriate treatment.
- Measures the effect of the given treatment.

PFT Procedure

1. Sit up straight
2. Get a good seal around the mouth piece
3. Rapidly inhale maximally
4. Without any delay blow out as hard as fast as possible (blast out)
5. Continue the exhale until the patient cannot blow no more
6. Expiration should continue at least for 6 sec (in adult) and 3 sec (children under 10 years)
7. Repeat at least three technically acceptable times (without cough, air leak and false start).

Spirometry

In order to do spirometry, an instrument that is spirometer is used. Spirometer measures the air capacity of the lungs. It is based on the measurement of the pattern of air movement in and out of the lungs during controlled ventilatory maneuvers. Spirometer is used to measure the air flow, ventilatory regulation, ventilatory mechanics and lung volume during a forced expiratory maneuver from full inspiration (Fig. 3.39).

Lung Factors Affecting Spirometry

Mechanical properties:

- **Compliance:** Describes the stiffness of the lungs
- Change in volume over the change in pressure
- **Elastic recoil:** The tendency of the lung to return to its resting state
- A lung that is fully stretched has more elastic recoil and thus larger/maximal flows of gas
- **Resistive elements:** Resistive properties are affected by: Lung volume, age, sex, height and weight, race, disease, bronchial smooth muscles
- Lung volume and peak expiratory flow rate peak expiratory flow **(PEF) or peak expiratory flow rate**

Fig. 3.39: Spirometers

(PEFR) are measured to differentiate obstructive or restrictive problems.

Clinical Approach

Forced expiratory maneuver is the common clinical approach. Results are found in patient's chart/monitor. Common spirometric values are:

• Forced expiratory volume in 1 second (FEV1)

FEV1 is the volume of air that can forcibly be blown out in one second, after full inspiration. Average values for FEV1 in healthy people depend mainly on sex, age height and mass.

Values between 80% and 120% are considered normal.

• Forced vital capacity (FVC)

Forced vital capacity (FVC) is the volume of air that can forcibly be blown out after full inspiration.

• FEV1/FVC ratio (FEV1%)

FEV1/FVC (FEV1%) is the ratio of FEV1 to FVC.

In healthy adults, this should be approximately 75–80%.

• Forced expiratory flow (FEF)

Forced expiratory flow (FEF) is the flow (or speed) of air coming out of the lung during the middle portion of a forced expiration.

It is generally defined as fraction.

The usual intervals are 25%, 50% and 75% (FEF25, FEF50 and FEF75).

Golden Points

Respiratory system

- Organs of respiration are nose, nasopharynx, larynx, trachea and bronchi, lungs in pleural cavity and muscles of respiration.
- External nose only contains nasal bones, rest are hyaline cartilages.
- Sphenopalatine artery is the artery of epistaxis.
- Nasopharynx contains lymph nodules of Waldeyer's ring. This ring includes lingual tonsil, palatine tonsil, tubal tonsil and nasopharyngeal tonsil.
- Air passes from nasal cavity → nasopharynx → oropharynx → larynx → trachea.
- Posterior cricoarytenoid is the safety muscle of larynx as it is the only muscle causing abduction of vocal cord.
- Epiglottis is made of elastic cartilage and it does not calcify.
- Bronchopulmonary segment is a pyramidal shaped part of lung aerated by a tertiary/segmental bronchus, its arterial supply is segmental and independent while the vein is intersegmental.
- There are 10 bronchopulmonary segments each in both right and left lungs.
- Thoracic cavity increases its anteroposterior, transverse and vertical diameters.
- During inspiration, the intrapulmonary and intrapleural pressures are lowered. At the end of inspiration, they increase to normal levels. During forced expiration, the pressures become higher than normal.
- External respiration is exchange of gases between the blood and the alveoli of lungs. Internal respiration is exchange of gases in the tissues.
- Oxygen level in pulmonary artery blood is 5.3 kPa, while in pulmonary vein blood O_2 level is 13.3 kPa.
- Arterial end of capillary to tissue contains pO_2 13.3 kPa, while venous blood returning from tissue, level of O_2 is pO_2 5.3 KPa.
- Respiration is controlled by inspiratory center in medulla. It controls rate and rhythm of breathing.
- Pneumotaxic center in pons inhibits inspiratory center, while apneustic center in pons promotes inspiration. The peripheral chemoreceptor is carotid body innervated by IX, X and sympathetic nerves. It stimulates respiration when there is ↓ pH, ↓ O_2 levels and ↑ CO_2 levels.
- Phrenic nerve (C4) innervates thoracoabdominal diaphragm, responsible for 60–70% respiration.
- Surfactant is lipid substance created by type II alveolar cells. It prevents the alveoli from collapsing.
- Pleural effusion is collection of fluid in the pleural cavity. It is mostly due to tuberculosis (TB), is the most common disease in our country. TB lungs is mainly caused due to smoking, poverty etc.

Clinical Aspects

Diseases of Lungs

Tuberculosis

- TB is a bacterial infection. Bacteria can spread through air. It is the commonest lung infection in developing countries. Occurs due to overcrowding, poverty, poor hygiene, ill nourishment, etc.
- Initially, there is infection by tubercular bacilli in the apex of lung. These bacilli are surrounded by macrophages and lymphocytes. The lesion sealed off is 'Ghon foci'. The infection reaches the regional lymph nodes and the Ghon foci and lymph nodes are called 'primary complex'. These get calcified and are visible on X-rays.
- The secondary tuberculosis may occur many years later due to aging, malnutrition, etc. There is cavitation in lung, loss of weight, night sweats and blood with cough (haemoptysis). Some of them

develop TB in other organs as well. Its classification is tabulated as follows.

Class	*Description*
Miliary TB	Infection carried by blood spreads the bacilli in many tissues of the body, e.g. lymph nodes, CNS, bones, joints. There are small nodules in lungs which appear like 'millet seeds'. This type of TB spreads to people around if untreated
Joint and bone TB	Hip and knee joints are mostly affected. There is destruction of articular cartilage, neighboring bone, leading to TB osteomyelitis
Lymph node TB	Next to lung, TB lymph nodes is very common. Cervical, axillary and inguinal lymph nodes are mostly affected. The lymph nodes get swollen but are painless
TB of intestines	Another site is TB of intestines, especially ileocecal junction. There is stasis of chyme, causing the chronic infection of tuberculosis. On healing, it leads to constriction/ narrowing of intestines. At times this region may have to be removed
TB of CNS	Tubercle bacilli may reach meninges and central nervous system, causing meningitis and many problems of functions of CNS. Even after treatment, there may be many functional deficits

- TB caused by *Mycobacterium tuberculosis* is contagious. Bacteria can spread from an infected person to someone else. One can get TB by breathing-in air droplets from a cough or sneeze of an infected person. There are three stages of TB: Exposure, latent and active disease.
- TB skin test/blood test can diagnose the disease.
- TB primarily attacks lungs. It can spread to other organs, pulmonary TB is curable with an early diagnosis and proper treatment.

Symptoms

- Chest pain, coughing, breathlessness, cough of more than 3 weeks.
- Latent TB can progress to active TB if preventive treatment is not given.
- Tuberculin intradermal injection can be given if one has TB. Chest X-ray and sputum test have to be done.
- TB is one of world's deadliest diseases. It is a leading cause of death among people who have HIV.
- Latent cases can be active in persons with weak immune system or persons with HIV.

Signs and symptoms of active TB: Coughing for more than 3 weeks; coughing up blood or mucus, chest pain or pain with breathing, weight loss, fatigue, fever night sweats, chills.

- Bone and joint TB and latent TB do not produce cough. CT scans show centrilobular nodules in 95% active TB cases. Lymph nodes have low density centers with rim enhancement. It is crucial that people seek medical attention if they have symptoms of TB or had contact with anyone who has active TB. The disease is fully treatable when a person gets an early diagnosis.
- People who get infected with TB but do not feel sick or have no symptoms are said to be have latent TB. Latent TB is not contagious but it can develop into active TB. People with active TB begin to feel better after a few weeks of treatment.

Prevention

- TB is partly preventable by vaccine. It spreads easily.
- Vitamin D helps in TB infection recovery. Breathing exercises done regularly to build ability to ventilate damaged lung and improve lung's function.

TB Association of India Recommendations

- Multidrug resistant-TB is a form of TB caused by bacteria that are resistant to treatment with at least two of the most powerful firstline anti-TB drugs, i.e. isoniazid and rifampicin.
- XDR-TB refers to MDR-TB strains that are resistant to the fluoroquinolones and second line injectable drugs.
- Treatment of MDR-TB should be 5–7 months followed by continuation phase, so that total duration of treatment is 15–24 months after sputum culture conversion. The drugs should be taken daily and patient should always be on DOTS (directly observed treatment short course).

MDR-TB Treatment

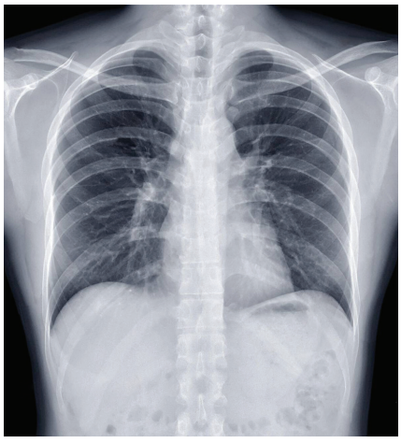
Multidrug resistance-TB is common in India. The treatment regimen includes 4–6 months' intensive phase with 7 drug regimen followed by 5-month course of 5 out of 7 drugs.

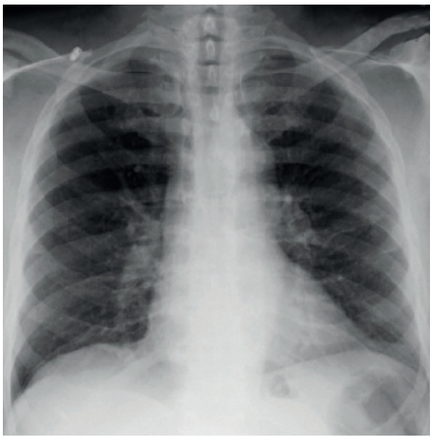
Diagnosis

- X-ray appearance in TB lung.
- Inactive TB—fibrosis, persistent calcification, Ghon's focus and a tuberculoma.
- Small nodules, branching linear opacities, patchy consolidation and cavitation. TB involves upper lobes and superior segment of lower lobe. PA chest X-ray is standard view used. Typical findings—2–4 mm centrilobular nodular opacities in upper area of lung toward the back.
- TB is a public health problem worldwide.
- Upper lobe TB is common due to better air flow or poor lymph drainage.
- There is relatively higher O_2 tension and delayed lymphatic drainage in these areas. Apicoposterior segment of upper lobe and superior segment of lower lobe are mostly affected.

CT scan: Centrilobular small nodules, branching linear opacities, patchy consolidation and cavitation are seen by CT scan.


Normal PA view of the chest


Pulmonary tuberculosis X-ray


Miliary tuberculosis

Diphtheria

It is caused by the bacteria *C. diphtheriae*. The membrane formed in the disease obstructs the air passage and is a serious condition.

Bronchitis

- The bacterial infection associated with common cold extends down into the trachea and the bronchi, causing 'bronchitis'. It may be acute or may become chronic.
- The infection may extend further into the lungs causing **bronchopneumonia**.
- Bronchitis is common in smokers.

Pneumonia

- It develops due to colonization of the lungs by microorganisms.
- It may develop due to impaired coughing, damage to ciliary epithelium of respiratory tract, pulmonary edema and decreased resistance to infection.
- **Lobar pneumonia** results from infection of one or more lobes of lung by *Streptococcus pneumoniae*.
- It is treated by antibacterial drugs.
- **Bronchopneumonia** results from spread of infection from bronchi to terminal bronchioles and alveoli.

Asthma

- This starts as an allergic process with superadded inflammatory reaction.
- Person finds expiration rather difficult, due to bronchospasm (contraction of bronchial muscle) and excessive secretion of mucus in the bronchial tree.

Cancer of the Lung

- Cancer of the bronchi is common in active or passive smokers.
- In smokers, the cancer of lung is far more common than non-smokers.
- The cancer cells may spread to lung tissue, liver, brain and bones. It is usually fatal.

Pneumothorax

- There is air present in the pleural cavity. It may occur spontaneously or as a result of trauma.
- **Spontaneous pneumothorax** may occur because of unknown cause or is secondary to pleural rupture due to lung disease, e.g. emphysema, asthma, tuberculosis.
- In **traumatic pneumothorax**, fractured rib may penetrate into the pleura, allowing air to enter the pleural cavity, causing collapse of the lung and respiratory distress.

Hemothorax

Presence of blood in the pleural cavity is called hemothorax. It may be secondary to injury to the chest or erosion of blood vessel by a malignant tumor.

Pleural Effusion

- It is excess of fluid in pleural cavity. It may be caused by increased hydrostatic pressure, increased capillary permeability or decreased plasma osmotic pressure.
- It usually occurs in TB lungs.
- *Words used in relation to **exchange** and transport of oxygen and carbon dioxide.*
  - **Eupnea** means normal quite breathing.
  - **Pulmonary ventilation** means the movement of air in and out of the lungs. It is also called breathing.
  - **Hypoventilation** means slow and shallow breathing.
  - **Hypoxia** means decreased amount of oxygen in the tissues.

Carbon Monoxide–Hemoglobin Dissociation Curve

- This curve is almost identical to the oxygen–hemoglobin dissociation curve except that the carbon monoxide partial pressure is at a level 1/250 of those for the oxygen–hemoglobin dissociation curve.
- Carbon monoxide partial pressure of only 0.4 mm Hg in the alveoli, allows the carbon monoxide to compete equally with the oxygen for combination

with the hemoglobin and causes half the hemoglobin in the blood to become bound with carbon monoxide instead of with oxygen. Therefore, a carbon monoxide pressure of only 0.6 mm Hg can be lethal.
- *Treatment of carbon monoxide poisoning* is achieved by administering pure oxygen because oxygen at high alveolar pressure can displace carbon monoxide rapidly from its combination with hemoglobin.

Tracheostomy

Tube is put through an artificial opening made in the trachea. Foreign body enters commonly in the right bronchus as it is shorter, wider and in line with the trachea.

Cyanosis and Anemia

- Cyanosis is defined as bluish coloration of skin and mucus membrane (Figs 3.40A and B).
- It occurs due to the presence of large amount of reduced hemoglobin in the blood.
- The cyanotic discoloration is due to the dark color of the compounds.

Modified Respiratory Movements

These movements are as follows:
- **Coughing:** It is a sudden reflex to remove secretions or foreign particles from the respiratory passages. It consists of three phases. These are—deep and long inspiration, strong expiration and a loud release of air through the just opened glottis.
- **Sneezing:** The muscles contract strongly to expel air with droplets of fluid through the air and mouth. More air is expelled through the mouth than the nose so that the blast of air does not injure the delicate conchae of the nose.
- **Yawning:** This is a reflex with deep inspiration followed by deep expiration with open mouth. It is due to boredom or tiredness and is contagious.
- **Crying:** There is shedding of tears from the eyes due to emotional reasons. There is inspiration followed by short expirations.
- **Laughing:** It is an expression of happiness or joy. The respiratory movements are same as in crying but the expressions of the face and body are different.
- **Hiccupping:** It is a spasmodic contraction of the thoracoabdominal diaphragm. There is a sound of 'hic' during inspiration. The reasons may be central or peripheral. It may be due to uremia or there may be local factor.

Problems Associated with Nose

- The nasal bone often gets **fractured** as the two nasal bones form the prominence of the nose.
- The nasal septum may be **deviated** to one or other side, causing asymmetry in the dimension of nasal cavity. Picking of the lower part of nasal septum may cause bleeding from the nose, called the **epistaxis**.
- **Nasal cavity** is prone to **common cold**. It is caused by the rhino-virus and is a mild, but irritating disease. One is not too ill, but not too well as well. It takes about one week for cold to be alright.
- **The paranasal sinuses** are draining into the nasal cavity. The infection from the nasal cavity reaches the sinuses to cause **sinusitis**. Maxillary sinusitis does not heal fully, as it is not able to drain completely. Postural drainage is advised in addition to other treatment.
- Infection of palatine tonsils is called **tonsillitis.** Infection of nasopharyngeal tonsil is called **adenoids.** The adenoids obstruct normal passage of air, so the child breathes through the mouth.

Assess Yourself

Long Answer Question

1. Discuss the various parts of respiratory system.

Short Answer Questions

1. Name the bronchopulmonary segments of right lung.
2. How is respiration controlled?
3. Write a short note on tuberculosis of lung, small intestine, and DOTS.

Multiple Choice Questions

Tick (✓) the correct option in the following:

1. Which of these body systems is involved in the removal of carbon dioxide?
   a. Respiratory system b. Digestive system
   c. Urinary system d. Reproductive system
2. Trachea is lined by:
   a. Stratified squamous epithelium
   b. Ciliated columnar epithelium
   c. Simple columnar epithelium
   d. Pseudostratified columnar ciliated epithelium
3. Normal tidal volume in adult is about:
   a. 300 ml
   b. 500 ml
   c. 1200 ml
   d. 3600 ml
4. Muscles used in quiet respiration are all, except:
   a. Internal intercostal muscles b. External intercostal muscles
   c. Diaphragm d. Sternocleidomastoid muscles
5. Angles of right and left bronchi at carina are:
   a. 20° and 40° b. 25° and 45°
   c. 40° and 40° d. 45° and 25°

Answer Key

1. a 2. d 3. b 4. d 5. b