CHAPTER FOUR
Respiratory System

Every living cell in an organism consumes oxygen. Oxidation of substances within the cells results in the liberation of heat and other forms of energy and in the production of carbon dioxide. This product of metabolism, unless removed from the vicinity of the cell and then from the organism, acts as poison which is harmful to protoplasm and quickly inhibits cellular activity. To stay alive, animals must take in oxygen and release excess carbon dioxide throughout their life. The exchange of gases between an organism and its environment known as respiration, which happens in 2 phases: External or organismic respiration (inspiration and expiration) and internal or cellular respiration.

I. External respiration is the exchange of gases (oxygen and carbon dioxide) between environmental air or water and the blood in the capillaries of the main respiratory organs or surfaces (mainly gills and lungs).

II. Internal respiration is exchange of gases (oxygen and carbon dioxide) between the capillaries of the circulatory system and the tissues or all body cells. Although the **respiratory** and **circulatory systems** are presented separately but they represent an integrated system.

Types of respiratory organs or surfaces

Respiratory organs are the main or essential portion of the respiratory system which serving to facilitate the external phase of respiration. The chief organs of external respiration in adult vertebrates are: i. Gills, external gills and internal gills; the ii. oropharyngeal mucosa; iii. lungs; vi. swim bladders and v. the skin. Embryos employ a variety of respiratory surfaces including extraembryonic membranes.

Respiratory process requirements

The respiratory process to be done efficiently, the following things must be available:

1. Efficient wide vascular respiratory surface.
2. Provision must be made for renewing the supply of oxygen-containing medium (air or water) which comes in contact with respiratory surface and for removing of carbon dioxide given off from the surface.
3. Respiratory medium as blood or lymph.
4. Oxygen carrier as hemoglobin, which consider as a respiratory stain.
5. Blood in the capillary network, of the respiratory surface, must circulate freely.

Criteria or adaptations of the respiratory surfaces for gas exchange

Respiratory surfaces must possess certain characteristics to process respiration efficiently: wide, thin, moist and highly vascular.

1. A large, vascular surface area must be provided that an example capillary network may be exposed to the environment to facilitate transport and exchange of respiratory gases.
2. The membranous surfaces through which gaseous exchange occurs must be moist by the surrounding water, because oxygen and carbon dioxide are dissolved in the fluid that bathes the cells of the respiratory surfaces.
3. Respiratory surfaces must also have thin walls through which diffusion can easily occur.

Pharyngeal pouches and slits

In the embryo of all chordates a series of pouches develops on either side of the pharynx in a form of endodermal lining evaginations, which are push gradually outward through the mesenchyme until they come in contact with the grooves (invaginations) of the body of the embryo (outer ectoderm). The process of evagination and invagination continue and soon, only a thin membrane, the branchial plate separates the groove (invagination) from the pouch (evagination). Except in amniotes, perforations or rupture of these plates usually occur so openings or passageways formed. The visceral or pharyngeal pouches are then called clefts or even pouches. The openings connecting the pharynx proper with the clefts are called internal gill slits; those connecting the clefts with the outside are external gill slits. The number of the pharyngeal pouches or clefts is greatest in lowest groups of vertebrates and least in the higher classes. Pharyngeal pouches are often bear gills.

Pharyngeal or visceral arches (gill arches)

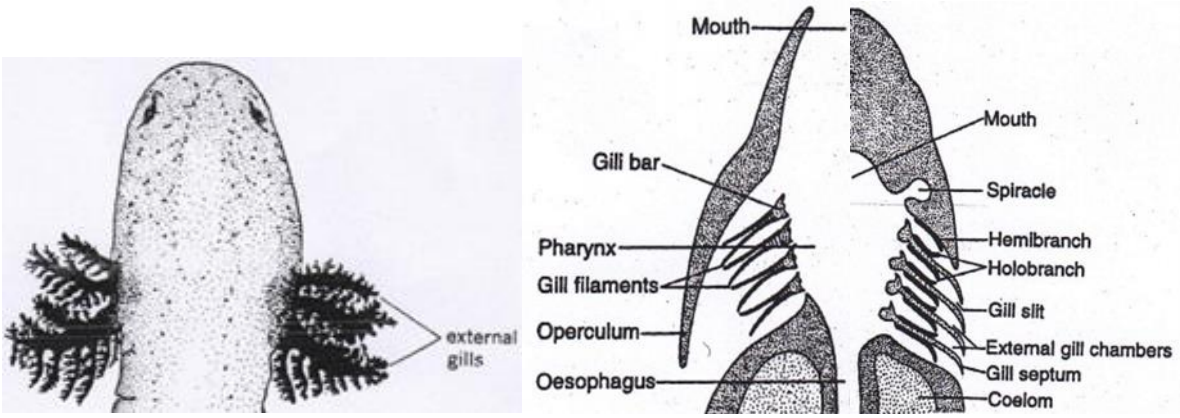
The visceral clefts are separated from one another by septa, which are mesodermal structure covered with epithelium derived either from ectoderm or endoderm, depending upon whether it is toward the exterior or interior surface. Within each septum lies a cartilaginous or bony barlike structure, the pharyngeal or visceral arch. This serves to support the septum. Blood vessels called aortic arches branch from the ventral aorta and course through the septa. The visceral arches, which make up the so-called visceral skeleton, are modified in higher vertebrates to form various portions of the skeleton in the head region. The aortic arches also undergo marked changes in the different classes.

Respiratory organs and their development

1. Gills. These respiratory surfaces are composed of numerous **gill filaments** or **gill lamellae**, which are thin-walled extensions of epithelial surface. They are supported by skeletal elements, the **branchial, pharyngeal or visceral**, **arches**. Blood is brought very close to the surface, thus facilitating a ready exchange of gases. The two types of gills are:

i. External gills. They are branched; filamentous capillary beds develop from the integument covering the outer surface of the visceral arches and covered entirely with ectoderm. They are not associated with visceral clefts or pouches. The function of the external gills poses no problem since their filaments protrude into the surrounding water. They are found in the larvae of many vertebrates, including lungfishes, some actinopterygians and amphibians.

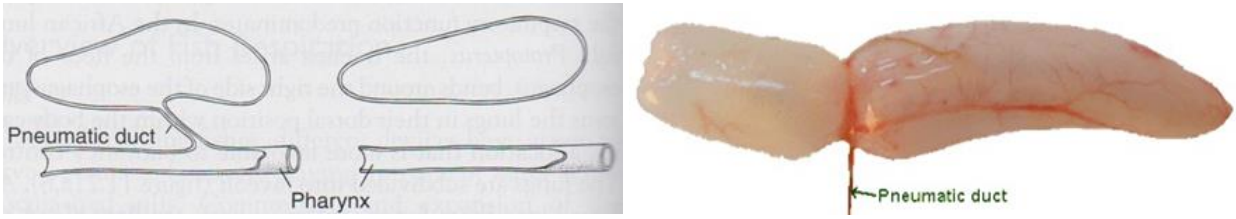
ii. Internal gills. They are associated with pharyngeal clefts or pouches. Often they are covered and protected laterally by soft skinfolds, such as **interbranchial septum** in chondrichthyes fishes (Fig. A), or by a firm **operculum**, as in many osteichthyes fishes (Fig. B). They usually composed of a series of parallel **gill lamellae** in a few form they may be filamentous. When the gill lamellae borne one both side of the interbranchial septum the gill is perfect and called **holobranch gill**, but if they borne on one side only it is called **hemibranch**. The hemibranch of each complete gill bounding a gill cleft or pouch are belong to different holobranch gill.



A **B** **C**

FIGURE 1: A. External gills, B- Complete holobranch gills of bony fish covered and supported by gill cover (operculum), C. Complete holobranch gills of shark and its gills are covered and supported by interbranchial or gill septum.

2. Swim or gas bladder. It is a gas-filled diverticulum which arises from the pharyngx and may open in it, through a duct, dorsally, ventrally (in physostomous type) or not at all (in physoclistous type). It may be single sac or divide by transverse constriction into a small anterior chamber and large posterior chamber, which are interconnected with each other. Air bladder lies in the body cavity, but outside coelom, above the gut and ventral to the vertebral column and kidneys. The swim bladder is missing in some bottom-dwelling and deep-sea bony fish (teleosts) and in all cartilaginous fish (sharks, skates, and rays).



A **B**

FIGURE 2 : Two types of swim bladders; A. physostomous; B. physoclistous type.

Two kinds of swimbladders

i. Physostomous gas bladder. A connection is retained between the swimbladder and the gut, the pneumatic duct, allowing the fish to fill up the gas bladder by "gulping" air and filling the swim bladder. Excess gas can be removed in a similar manner. This condition is called physostomous and species that have this kind of air or gas bladder are called physostomes.

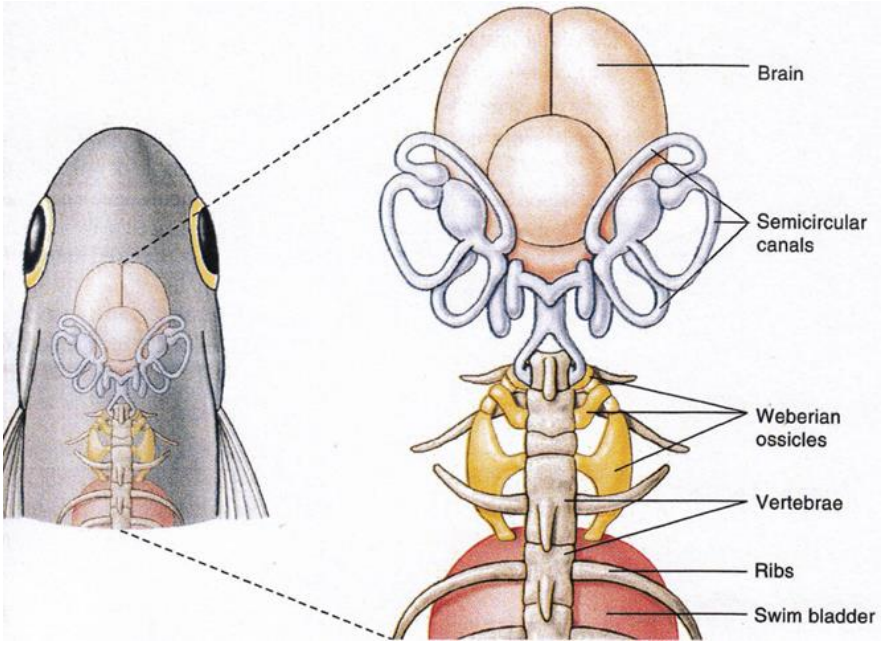
ii. Physoclistous swimbladder. In other species the connection with the gut is closed and no gas can be moved from the gut to the swim bladder, this is called the 'Physoclistous' condition. In early life stages, fish have to rise to the surface to fill up their swim bladders, however, in later stages the connection disappears and the gas gland **'rete mirabile'** has to introduce gas (usually oxygen or nitrogen) to the bladder to increase its volume and thus increase buoyancy. Rete mirabile (Latin for "wonderful net"; plural retia mirabilia). Gas exchange is through the capillaries of rete mirabile and the membrane of the bladder.

Functions of the gas bladder

i. Hydrostasis to provide neutral buoyancy as an ***equilibratory organs***. When gas bladders function as hydrostatic organs, they are called swim bladders, enabling the fish to swim in different water levels with little efforts.

ii. Respiration. In some species gas bladders have retained or secondarily acquired a respiratory function; i.e., they use their gas bladders as lungs. In this case gas bladder is called ***respiratory gas bladder***, as in dipnoans (lungfishes).

iii. Sound reception. The swim bladder of some teleosts participates in sound detection by the aid of Weberian apparatus which comprises four bony elements or **Weberian ossicles**, derived from parts of the anterior vertebrae, which via their ligamentous connections form a chain linking the swim bladder to the inner ear. The function of the Weberian ossicles is therefore in some respects analogous to that of the middle ear ossicles of terrestrial vertebrates



3. Lungs and their ducts

The diverticulum which in the embryo gives rise to lungs grows out from the floor of the pharynx posteriorly. It soon divides into lung buds which give rise to the bronchi and lungs. The lung buds grow posteriorly until they reach their final destination. They may branch to varying degrees, depending on the species. The original unpaired duct which connects the lung to the pharynx becomes the trachea. In tetrapods, its anterior end becomes modified to larynx, which opens into pharynx through a slit-like glottis. The lower end of the trachea usually divides into two bronchi which lead to the lungs. The skeletal elements of the larynx are derivatives of certain visceral arches which have become modified. No such structures are to be found in association with the pneumatic ducts of fishes.

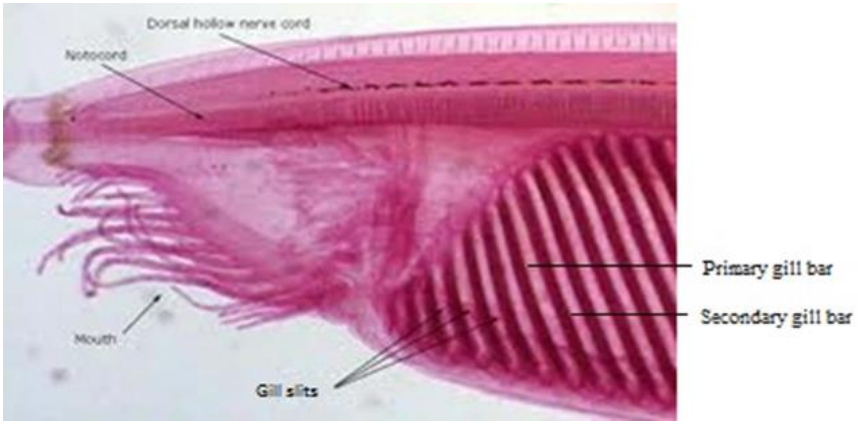
4. Skin

Although the gills and lungs are the primary respiratory organs, the skin can supplement breathing. Respiration through the skin, referred to as cutaneous respiration, can takes place in air, in water, or in both. Amphibians rely heavily on cutaneous respiration, often developing accessory skin structures, such as folds and papillae, to increase the surface area available for gas exchange.

Comparative Anatomy of the Respiratory System

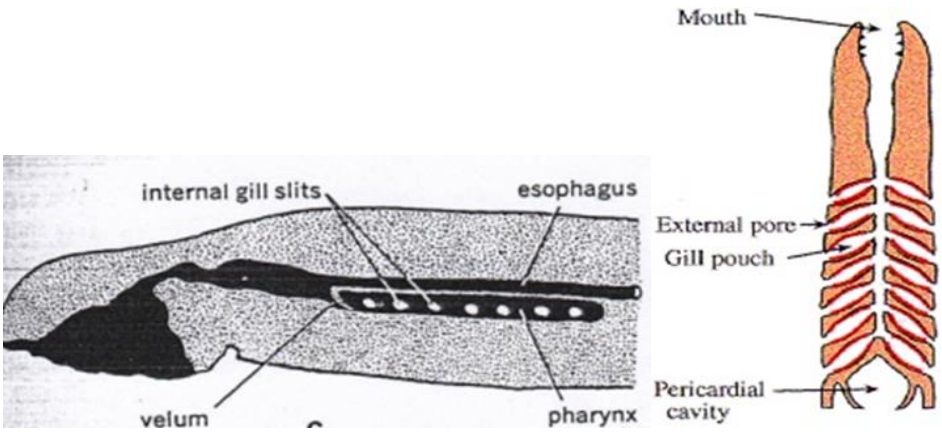
Amphioxus

Although much of respiration of amphioxus takes place through the skin, blood in the gill bars (primary and secondary gill bars), in the wall of pharynx, is oxygenated by the stream of water passing from mouth to pharynx through the gill slits to the atrium and leaving through the atriopore.



Lamprey

In contrast to larva, the esophagus and the pharynx of adult become separated in such a manner that each has its own connection with the mouth. The esophagus then lies dorsal to the pharynx. The pharynx becomes a blind pouch.



seven pairs of gill pouches, which are rather large and spherical. Each gill pouch is borderd by a hemibranch on both anterior and posterior walls. There are thus 14 hemibranchs on each side but only 6 holobranch gills on each side, since the first and last hemibranchs are not parts of holobranchs. During respiration the lamprey usually forces water in and out the gill clefts through the external gill slits. Thus

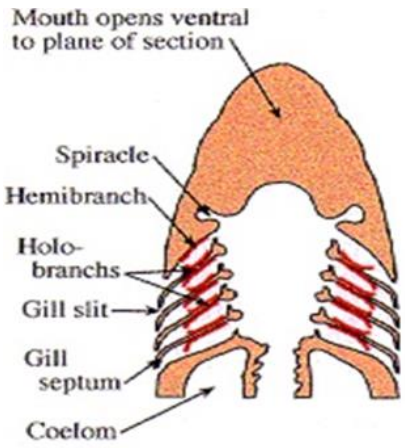
the gill lamellae are bathed by a constantly replenished supply of water. This is quite in contrast to the method employed by true fishes, in which water enters the mouth and passes over the gills on its way to the outside through the external gill slits or openings. The method used by lamprey is necessary, and an adaptation for its parasitic mode of feeding, because when the animal is attached to some object or engaged in feeding, the mouth opening is blocked.

Fishes

Visceral or branchial arches encircle pharynx, in fishes they serve primarily to support the gills. They are located between the gill pouches at the base of interbranchial or gill septa. The first is called mandibular arch, the second the hyoid arch, the remainder being referred to by number (1, 2, 3, 4, etc.). As it mentioned before, in gnathostomes (fishes and tetrapods), mandibular arch modified to jaws and hyoid arch support them.

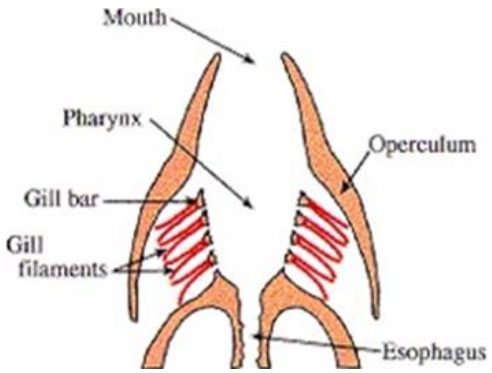
Dogfish, which represent cartilaginous fishes, the **gill pouches** are five pairs, located in the lateral walls of the pharynx. Each two adjacent pouches are separated by **interbranchial** or **gill septum**. The pharynx **gill arches** are five in number lie at the inner portions of the gill septa. The mucous membrane lining the gill raised into a series of highly vascular, horizontal folds, the **branchial** or **gill lamellae** which in turn arranged on both sides of each gill septum. The first gill pouch lies between the hyoid and the first branchial arch. The last pouch lies between the fourth and fifth branchial arches.

The hyoid arch supports a hemibranch (**half gill**), as it bears gill lamellae only on its posterior border. The first four arches carry four holobranchs, the fifth branchial arch is without gills. The gill pouch, or cleft, lies between the mandibular and hyoid arches and is often called hyomandibular cleft. In dogfish and most other elasmobranchs it forms a reduced gill, **pseudobranch** or **spiracle**. It is closed in other fishes.



Septal gills of dogfish. 5 gill pouches on each side; first gill is hemibranch while other 4 are holobranch.

Bony fishes, have only four gills. They are not enclosed in gill-pouches because the gill-septa are very short. Consequently there are no such gill-lamellae as in the dogfish, but loose gill-filaments which hang down from the gill-arches into the branchial chamber on each side. Two rows of such filaments are attached to each gill-arch. From the anterior border of each arch project two rows of short teeth-like processes called the gill-rakers. They serve to protect the delicate filaments from the ill-effect of silt material which they strain from the respiratory water current. There are only four complete gills or holobranchs inside each branchial chamber. The septum of the hyoid arch is enormously developed and extends caudad as the operculum, cover for the branchial chamber in both sides.



Opercular gills of teleost. Four complete gills or holobranchs inside each branchial chamber.

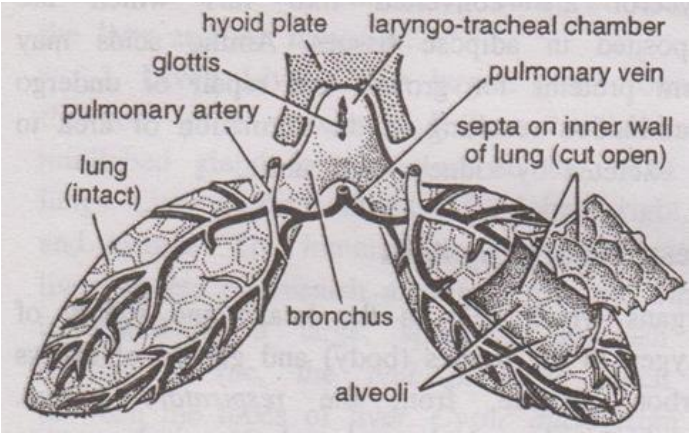
Frog

Most amphibians spend their larval life in water, and after a period of metamorphosis go to the land. Larval amphibians use external integumentary gills, in addition to the skin, as organs of respiration. In a few urodeles the gills are retained throughout life, but in most amphibians they disappear during metamorphosis. In most amphibians, including frogs, newly developed lungs usually take over the respiratory function. Cutaneous and buccopharyngeal respiration are also important in adults of this class.

Chief organs for pulmonary respiration in frog are two lungs. The passage through which air enters and leaves the lungs is called respiratory tract. It consists of **external nostrils, nasal chambers, internal nostrils, buccopharyngeal cavity, glottis, laryngo-tracheal chamber, two bronchi.**

two bronchi lead directly to the lungs. The two lungs are ovoid, thin-walled and highly elastic sacs suspended freely inside the peritoneal body cavity, one on either side of the heart. The inner surface of each lung is divided by a network of folds or

septa into many small air sacs or alveoli, while leaving a clear large central cavity. The alveoli lined with thin epithelium richly supplied with blood capillaries. As in frog, the inadequate supply of o2 obtained though the lungs is supplemented through moist skin and buccopharyngeal cavity.

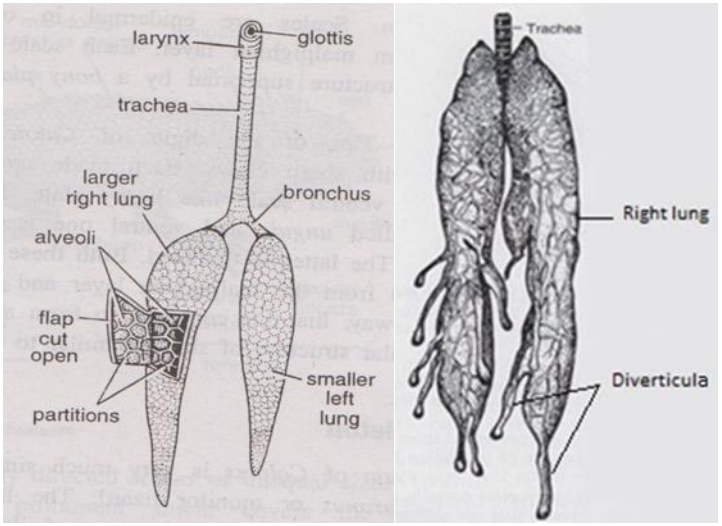


Frog pulmonary respiratory system.

Lizard

Chief organs of the lizard respiratory system are two lungs. The passage through which air enters and leaves the lungs is called respiratory tract. It consists of **external nostrils, nasal chambers, internal nostrils, buccopharyngeal cavity, glottis, trachea** and two **bronchi.**

Larynx. The skeletal support larynx contains of a pair of ***arytenoid cartilages*** and an ***incomplete cricoid ring***. In crocodilians another element, the thyroid cartilage, is present. Larynx opens is guarded, in certain lizards and turtles, by a fold of tissue may represent the beginning of an ***epiglottis.***

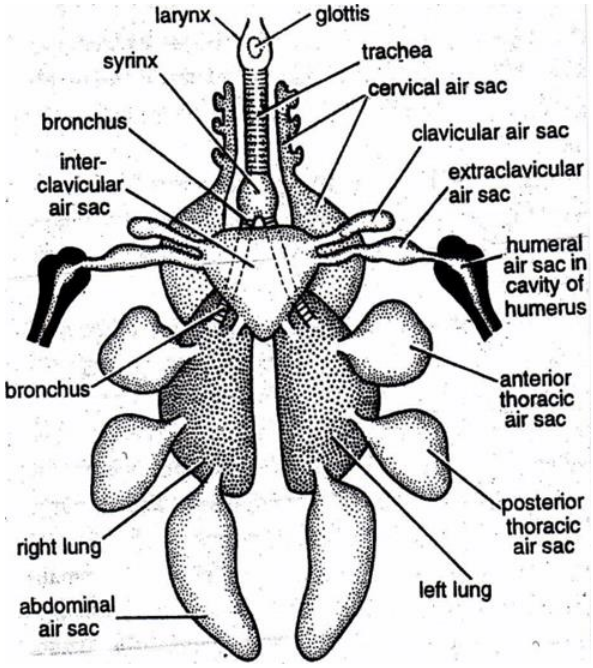


A **B**

A. Lizard respiratory system; B. Beginning of the appearance of air sac in the lungs of chameleon.

Birds

The intense activity of flight and high metabolism of birds demand large supplies of oxygen, thus birds are provided by special arrangement. Additional air stores, the **air sacs** attached to the main respiratory organ, **the lungs**. Bird's respiratory ducts in succession are: **external nares, internal nares, pharynx, glottis, larynx, trachea, syrinx** and **bronchi** (Fig.4.20).



Birds respiratory system.

Larynx. It is greatly reduced in birds. Larynx is supported by a ***cricoid cartilage*** and paired of ***arytenoid cartilages***. Vocal cords are absent so it does not produce sounds. Tracheal cartilages are usually in the form of complete rings. On entering the thoracic cavity, it expands into a syrinx and then bifurcates into two short bronchi.

Syrinx. At the base of the trachea, is found a special structure, the syrinx or voice box. It is characteristic of birds as it does not occur in other vertebrates. It is supported by the last three or four rings of trachea and the first half of each bronchus. The sounds are produced by vibration of its membranes, and intrinsic muscles, as the air expelled from the lungs during expiration.

Bronchi. They are two short tubes, at the base of the syrinx, one for each lung. They are supported by incomplete cartilaginous rings. Each of them, before entering the lung in its side, is called primary bronchus, and its portion within the lung proper is called the ***mesobronchus***. A number of ***secondary bronchi*** arise

from it. These then branch into numerous small tubes of rather uniform diameter, called parabronchi, which form loops connecting with other secondary bronchi.

The walls of the parabronchi consist of an anastomosing network of air capillaries, each only a few thousand of a millimeter in diameter, surrounded by blood capillaries. It is the lining of the air capillaries that constitutes the respiratory epithelium.

Lungs. The two bright-red lungs are small and compact. The lungs of birds differ from those of other groups and are probably the most efficient of all. They are very vascular and capable of little expansion, being firmly attached to the ribs and thoracic vertebrae; hence they do not hang freely in thoracic cavity.

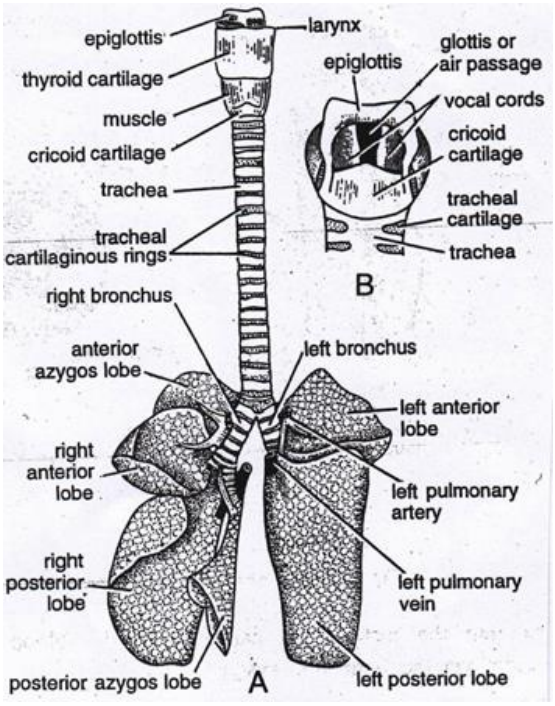
Air sacs. The mesobronchus and several (usually four) secondary bronchi continue on, through the walls of the lung and expand into large air sacs which ramify among the viscera and even enter the cavities of several bones. The air sacs do not furnish a respiratory surface, since their walls are smooth and have a poor blood supply. Moreover, they are furnished with oxygenated blood so they serve as reservoirs and take part in the movements of air during respiration. Air sacs may also play a significant role in temperature regulation by serving as an internal cooling device. Different species of birds show many variations in the detailed arrangement of the air sacs. The 9 major air sacs of pigeon named according to their location. ***2 Cervical air sacs***. They lie at the base of the neck; ***Interclavicular air sacs***. It is a single median air sac, connected with both lungs and lies between the two clavicles (furcula), on either side; ***Anterior thoracic air sacs.*** They are two in number and cover the ventral surfaces of the anterior part of the lungs; ***Posterior thoracic air sacs***. They are also two in number and lie posterior to the former; ***Abdominal air sacs***. The largest of the air sacs, two in number and they lie along the dorsal wall of the abdomen, ventral to the kidneys and amongst the coils of the small intestine.

Rabbit

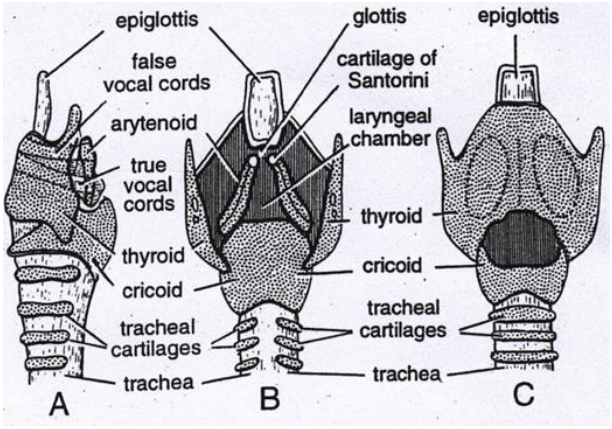
1. Respiratory tracts. It serves as the passage for the entry of fresh air into the respiratory organs (lungs) and the exit of foul air after gaseous exchange. It includes: **external nares, nasal chambers** (moist and warm the air), **internal nares, nasopharynx, glottis, larynx, trachea** and its branches(out and inside the lungs).

Larynx. Its wall is supported by four cartilages: the ***thyroid cartilage***, The paired ***arytenoid cartilages*** are form the dorsal or posterior boundaries of the larynx, stretching from them are two pairs of membranes, the false vocal cords anteriorly and the true vocal cords posteriorly which can be set in vibration to produce

sounds during the passage of air over them. Arytenoid and thyroid cartilages are articulated with the ***cricoid cartilage***, which is a complete ring around the base of the larynx. True cartilaginous ***epiglottis*** is present in mammals only. It is composed of elastic cartilage and extends upward from the thyroid cartilage in front of the glottis to cover it during the swallowing of food to prevent food entering.



Rabbit. A-Respiratory system in ventral view, B-Larynx and part of trachea in dorsal view.



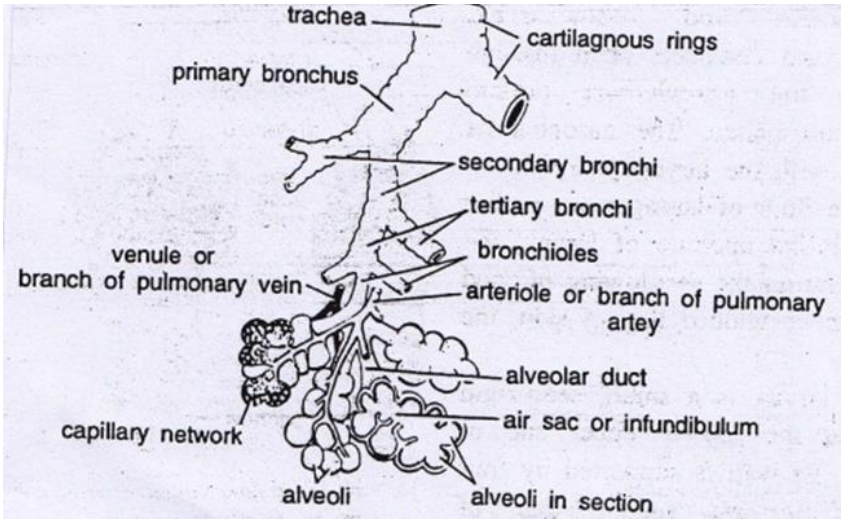
Rabbit. Different views of larynx. A-Lateral, B-dorsal, C-ventral.

Trachea. its wall is supported by C-shaped cartilaginous rings which are incomplete dorsally where the trachea lies against the wall of the esophagus. The two side of the cartilaginous ring are united by smooth muscles. The cartilages keep the tube from being constricted. The base of the lower end of trachea

bifurcates into two **primary bronchi** or right and left bronchi (singular: bronchus). They have the same structure as the trachea.

2. Respiratory organs. the lungs are lying in a special cavity, the ***pleural cavity*** and in most mammals subdivided externally into lobes, the number of lobes on the right side generally exceeds that on the left. Thus the man has three lobes on the right and two on the left. In rabbit the right lung consists of four lobes, namely the ***anterior azygous, right anterior, right posterior and posterior azygous***. The left lung consists of only two lobes, the ***left anterior*** and the ***left posterior.***

Each bronchus, as it enters the lung, divides and subdivides into finer and finer bronchus. The bronchioles which are the ultimate branches terminating in dilated air sacs. Air sacs bearing alveoli and around each alveolus is a network of capillary of blood vessels for gas exchange with environmental air which enters the lungs. The alveoli communicate with one another by apertures in their walls.



Intrapulmonary branches of the bronchus. The bronchioles which are the ultimate branches terminating in dilated air sacs bearing alveoli in their walls.